6

The Macmillan Science Series

Science for Tomorrow's World

Teachers' Annotated Edition

THE MACMILLAN SCIENCE SERIES *A NINE-BOOK SERIES FOR ELEMENTARY SCHOOLS*

SCIENCE FOR TOMORROW'S WORLD, BOOK 6

YOUR TEACHERS' ANNOTATED EDITION PROVIDES:

- *A Teachers' Guide, bound into the back of the textbook*

The Content and Process of Science Education (see guide pages 7 to 22)—This overview of science education in today's elementary schools explains the philosophy behind THE MACMILLAN SCIENCE SERIES, with emphasis on the *structure of subject matter* in the science curriculum and the *conceptual framework* of the series.

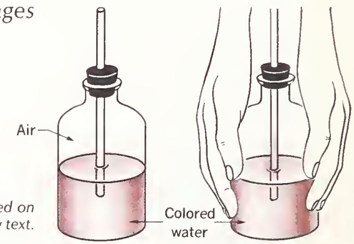
How Children Acquire Science Knowledge: A Developmental Approach (see guide pages 23 to 31)—Here is a practical discussion of the relationship between the teaching of science and the development of logical thought processes.

Some Problems of Method in Teaching Science (see guide pages 32 to 61)—This part of the guide covers such important topics as providing for individual differences and using community resources.

Overviews, Tests, and Directories (see guide page 62)—Here are overviews for each unit in the book plus the table of contents of each book in the SCIENCE FOR TOMORROW'S WORLD, BOOKS 1-6, series to appraise you of the place of your book in the series structure. This section also includes tests for each unit in the textbook and directories of publishers, film and filmstrip sources, and suppliers of source materials.

- *The Pupils' Textbook, with teaching suggestions printed beside the text pages and with annotations printed right on the text pages*

Fully developed lesson plans | Background information | Additional activities and demonstrations | Readings for the pupils and the teacher | Answers to the questions in the textbook | Checklist of science materials



An activity suggested on page 61 of the text.

SOME OF THE SPECIAL FEATURES YOU'LL FIND IN BOOK 6:

Units organized to teach the Key Concepts of science

SCIENCE FOR TOMORROW'S WORLD, BOOK 6, is built on the 10 Key Concepts of science that are described on pages 12—18 in the Teachers' Guide. Throughout the text, specific concepts lead the pupils toward deeper understanding of these Key Concepts. Unit 7, for example, helps pupils to understand:

The Key Concepts

When equilibrium is upset in organism-environment interactions, regulatory mechanisms go to work to restore equilibrium.

Man has changed and continues to change the natural environment; but because he is often ignorant of long-range consequences, his actions may have harmful effects for himself and for other living organisms.

Some of the Specific Concepts

1. Green plants link the earth's elements, the sun's energy, and living things (pages 236-241 and 294-297).

2. Plants are adapted to the environments in which they are found (pages 245-253 and 294).

3. Animals are adapted to the environments in which they are found (pages 254-257, 266, and 294).

4. As environments change, the types of plants and animals found there also change (pages 258-261, 266, 292, and 294).

5. Living things are interdependent (pages 262, 263, 266, 294, 296, and 297).

6. Man frequently upsets the balance among living things (263-266 and 292-294).

7. For maximum use of our land and oceans, there must be proper management of our resources (267-294 and 297).

Lessons, activities, and illustrations that teach pupils to think and work using the ways of the scientist

SCIENCE FOR TOMORROW'S WORLD, BOOK 6, provides numerous insights into the ways in which scientists think and work. Unit 8, for example, teaches the pupils to work out problems by:

Observing—(pages 300-311, 313, 316, 318, 320-322, 327, 331, 332, 334, 335, 340)

Experimenting (pages 311, 316, 319-322, 327, 328, 336)

Classifying (pages 330 and 331)

Communicating (pages 305, 306, 313, 314, 317, 318, 322, 331-334, 338-340)

Comparing (pages 305-308, 318, 320, 321, 327, 329, 330, 333, 335, 337)

Measuring (pages 327 and 328)

Explaining (pages 302, 305-307, 311, 313, 314, 316-322, 327, 328, 333-335, 337-340)

Hypothesizing (pages 311, 316, 319-320, 322, 325-328, 334, 340)

**For more special features,
turn to the inside back cover.**

THE MACMILLAN SCIENCE SERIES

SENIOR RESPONSIBILITY FOR THE SERIES
J. DARRELL BARNARD
SCIENCE EDUCATION

CELIA STENDLER
CHILD DEVELOPMENT AND ELEMENTARY EDUCATION

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UNDER THE EDITORSHIP OF
SIDNEY SELTZER

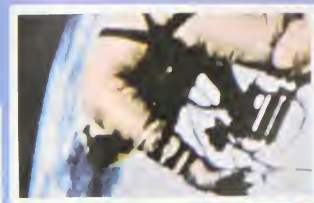
TEACHERS' ANNOTATED EDITION

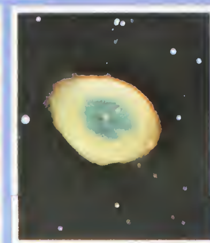
SCIENCE FOR TOMORROW'S WORLD: 1, 2, 3, 4, 5, 6
SCIENCE: A SEARCH FOR EVIDENCE 7
SCIENCE: A WAY TO SOLVE PROBLEMS 8
SCIENCE: A KEY TO THE FUTURE 9

Texts, Teachers' Annotated Editions, and other Complementary and Supplementary Teaching Materials

The TEACHERS' ANNOTATED EDITION consists of

- Teaching Suggestions
- Annotated text pages
- Teachers' Guide





THE MACMILLAN SCIENCE SERIES

Science for Tomorrow's World 6

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TEACHERS' ANNOTATED EDITION

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Teachers' Annotated Edition with Teaching Suggestions and Teaching Guide

12G

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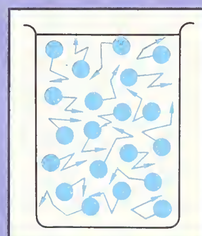
What's Ahead?



ABOUT THE TEACHING SUGGESTIONS

Teaching Suggestions, for each page in the pupil's textbook, are found on the outside of the page. The Teaching Suggestions include lesson plans, background material, the answers to the questions posed in the pupil's pages, additional activities, and bibliographies of books and films. The suggestions apply directly to the material on the pupil's pages and provide a ready reference for the teacher as he or she uses the textbook in class. Many pages have space on them for teachers to write in their own comments. A Materials Checklist is included in each book, containing ample space for teachers to add materials for experiments and demonstrations of their own.

PROFESSIONAL BOOKS FOR TEACHERS

Blough, Glenn O., *It's Time for Better Elementary School Science.* NSTA, 1958. 48 pp. Of special interest to administrators and supervisors. Theory for science curriculum construction.

Brandwein, Paul F., Fletcher G. Watson, and Paul E. Blackwood. *A Book of Methods.* New York: Harcourt, Brace, 1958. 568 pp. An excellent sourcebook.

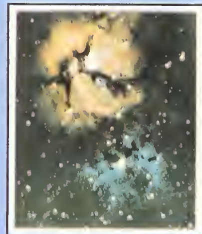
Deason, Hilary J., *Science Booklist for Children,* American Association for Advancement of Science, and NSF, Washington, D.C., 1960. 138 pp.

Hone, Elizabeth B., and Alexander Joseph, Edward Victor, and Paul F. Brandwein. *A Sourcebook for Elementary Science.* New York: Harcourt, Brace & World, 1962, 552 pp. An excellent sourcebook.

Stendler, Celia B., *Teaching in the Elementary School.* New York: Harcourt, Brace, 1958.

Victor, Edward, *Science for Elementary School,* New York: Macmillan, 1965.

Woodburn, John H. and Ellsworth S. Obourn, *Teaching and the Pursuit of Science,* New York: Macmillan, 1965.



California Journal of Elementary Education, Vol. 21, No. 2, November 1952. 63 pp. Special issue on science for every child and every teacher; characteristics of a good program, equipment, and materials.

Leadership for Science in the Elementary Schools. California Association for Supervision and Curriculum Development, 1960. 88 pp. A handbook for teachers, administrators, consultants, and supervisors.

Looking Ahead in Science. California State Department of Education, 1960. 88 pp. Report of the Production Seminar and Conferences on the Improvement of Science Education in the Elementary School Purposes, appropriate experiences and content, equipment and materials, scheduling, evaluation, pre- and in-service education.

Safety Through Elementary Science. Washington, D.C.: National Education Association, 1949.

Theory Into Action. NSTA, 1964. 48 pp. Discusses science curriculum development based on conceptual schemes.

UNESCO: Source Book for Science Teaching. New York: UNESCO, 1959. This volume has been revised, expanded, and reprinted in many editions.

KEY CONCEPTS

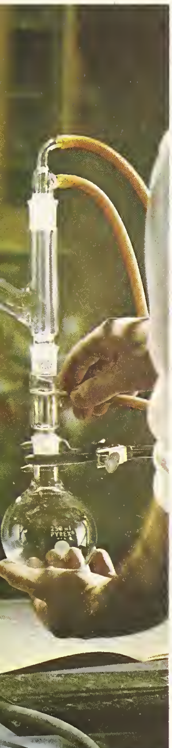
Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. The essence of measurement is unit iteration; to measure, it is necessary to establish a unit and to repeat that unit as often as necessary.
2. In order for us to be able to communicate about measurements, standard units are necessary; two standard systems, the English and the metric, are used.
3. Measures of matter include weight, volume and mass; mass is a measure of the quantity of matter in a substance.
4. Some measurements, such as speed, can be derived from other basic units.
5. To describe motion, we need to know both speed and direction; quantities that tell both are vector quantities.

The Scientist's Way



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Other concepts appear under "Learnings to Be Developed" in each lesson found in the Teaching Suggestions.

Measuring Things

Recording Measurements

What to Measure?

How Much Information?

6. Velocity is a vector quantity; it tells how fast and in what direction something is moving.
7. Some quantities stand for a change in another quantity in a given period of time; the change in speed along a path in a given period of time is called acceleration.
8. Graphs enable us to see various kinds of relationships.
9. On distance-time diagrams, the steepness of the straight line is an indication of speed; the greater the speed, the more the line rises in the same time.

PROCESSES:

- Observing—Pages 3, 4, 9, 10, 11, 16, 17, 18, 19, 20, 22, 23, 28, 29.
- Experimenting—9, 10, 23.
- Comparing—3, 4, 9, 10, 16, 17, 18, 19, 20, 22, 23, 28, 29.
- Inferring—7, 9, 10, 11, 16, 17, 18, 19, 20, 22, 23, 28, 29.
- Measuring—3, 4, 9, 10, 22, 23.
- Selecting—3, 13, 23.
- Communicating—3, 4.
- Demonstrating—3, 4, 14, 16, 17, 18, 19, 20, 22, 31.
- Explaining—3, 9, 23, 31.
- Hypothesizing—9, 10, 15, 23.

TEACHING SUGGESTIONS
(pp. 2–3)

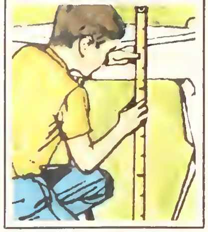
● **LESSON:** How accurately can things be measured?

Background: It is interesting that a great many measurements made with the same ruler or other measuring instrument will result in an average measurement that will be very precise. If you were to compute the average of all the measurements taken by the students of some object in the room—say, the overall length of the chalkboard—you probably would find that the average was a figure with a high degree of accuracy.

Learnings to Be Developed: Measurement is an important part of the scientist's work.

Developing the Lesson: Have the students measure a few objects in the classroom—tables, desks, the chalkboard, etc. The objects should have straight sides and end sharply. The students may use 12-inch rulers to take the measurements. The longer the objects being measured, the more the students' results will differ; therefore, make a point of choosing long objects.

How is it possible for you to have obtained different results when you measured the same things?



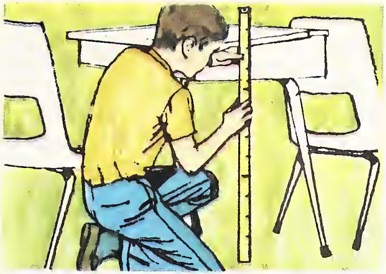
Men have been concerned with measurement for thousands of years. Through the centuries, systems of measurement were devised and improved, leading to the systems that we use today. There is still room for improvement. Today, as in the past, measurement is vital to almost all scientific investigation.

Recording Measurements

From the beginning of a new life the important measurements of time and size are recorded.

Measurements are used to build new ideas. Measurements also play an important part in our present knowledge about the world in which we live. Measuring things is often a daily part of a scientist's work. All scientists, no matter in what area of science they work—chemistry, biology, physics, geology—must be very careful and accurate. To be accurate so that other scientists can rely on their reports, scientists must use tools for measurement. Why is this so important?

Mr. and Mrs. Jasper Smith
ANNOUNCE THE ARRIVAL OF
Robert Louis Smith
ON **January 2, 1965**
WEIGHT **7 pounds 3 ounces** HEIGHT **19½ inches**



How high is your desk? To find out, measure the distance from the floor to the top of your desk. Make a record of your measurement, but do not show it to anyone. Now ask one of your classmates to measure the height of your desk. Ask him to write down his answer, but not to show it to anyone. Do the same with a second classmate and then a third.

Now compare the measurements. They probably will vary slightly. You may have recorded the height of your desk to the nearest half inch. Perhaps one classmate measured to the nearest inch. Maybe another classmate measured to the nearest quarter inch. Which measurement is correct? What if one person reports a measurement that is several inches different from all the others? What might have happened?

If the measurements were made carefully, each person may have obtained the "right" answer. For some purposes it is necessary to measure things to the nearest inch. Sometimes it is necessary to measure something to the nearest yard. At other times the nearest mile is enough. For example, guess how far it is from your house to your school. It certainly is not useful to know this distance to the nearest inch. If you live far away, the measurement to the nearest half mile tells you all you want to know.

On the other hand, if you want to know how much you have grown during the summer, you would need a measurement even more exact than one to the nearest inch. You would probably measure your height to the nearest quarter inch.

What kind of thing would you measure to the nearest foot? The nearest mile? The nearest eighth of an inch? The nearest 100 miles? The nearest million miles?

- *What must you do to get more accurate results?*

Follow-Up: Accuracy depends not only on the care taken in making the actual measurement, but also on the use of accurate measuring tools. One of the reasons the students may have obtained different results in their measurements is that their rulers probably were made to different standards of accuracy. If there is a cloth tape measure or a wooden yardstick available, have the students remeasure the same objects with these new instruments. They probably will obtain different results from those obtained with their rulers. You might then point out that taking very accurate readings is useless unless the measuring tool one is using is also accurate. You might also point out that the smaller the subdivisions marked on the ruler, the more accurate will be the readings that can be taken.

TEACHING SUGGESTIONS
(pp. 4–5)

LESSON: Why are standard units of measurement necessary?

Learnings to Be Developed:

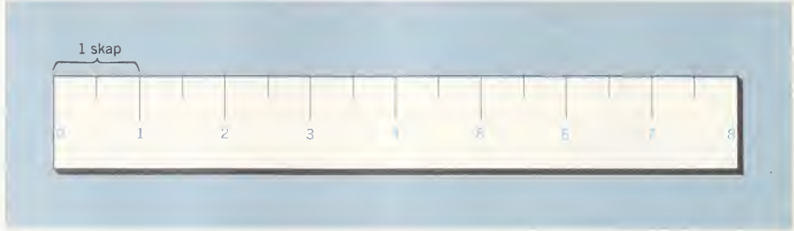
In order for us to be able to communicate about measurements, standard units are necessary.

Two standard systems, the English and the metric, are used.

Developing the Lesson: One can start by pointing out that in the United States almost everyone uses inches, feet, yards, and pounds to measure the sizes and weights of objects. One can travel anywhere in the United States and be sure that when he orders something by size or weight, he will always get the same amount.

- *What would be the effect if each state had its own system of measurement?*
- *Would the skaps, vons, jals, and squeeds described on these pages be adequate?*

Discuss the fact that different countries do use different systems of measurement, and this can be very confusing if one travels in a foreign country. Different kinds of money are perhaps the most obvious kind of difference that will occur to the students. If they do not realize it themselves, you can



You too can make up units of measurement. The ruler above is marked in units called *skaps*. What problems would arise if everyone made up his own units of measurement?

Standard Units

The picture shows a ruler you have never seen before. It is marked off in units called *skaps*. Make a ruler like this and measure the width of your desk. Measure the width as carefully as possible. How many skaps wide is your desk? Next measure the width of your hand using the same ruler. How many skaps wide is your hand?

Now, imagine that you are ordering a pair of shoes by mail. You measure your foot and discover it is four skaps wide at the widest part and eleven skaps long. You include these facts in your order. The shoe manufacturer receives your instructions. But, of course, he has no idea what size shoe to send you. He does not know the size of a skap.

Nobody in the world uses a skap as a unit of measure. The authors of this book made it up. You too can make up a unit to measure length. You can make the unit as long as you wish and you can name it anything you wish. You can make very careful measurements using your own units. You can even make up a measuring system with many new units based on your first unit. For example, you could say that four skaps are equal to one *von*, fifteen vons are equal to one *jal*, and six thousand jals are equal to one *squeed*. You could even find out how many squeeds it is, say, from San Francisco to Denver. But no one would know what you were talking about!

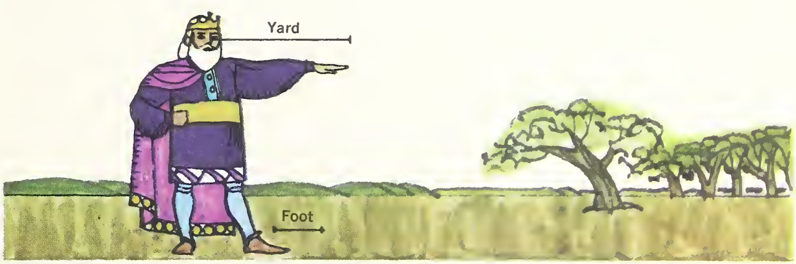
Anyone listening to you describe something as "fourteen jals long" would feel as confused as the shoe manufacturer who did not know the length of a skap.

In order to make sure that other people know what we mean when we report our measurements, we must all agree to use certain units of measure. We must agree on the exact value of these units. Units that everyone agrees to use are called **standard units.**

We all know how long an inch, a foot, a yard, and a mile are. But there is nothing in nature to tell us the *exact* value of the standard units we use. From where, then, did these units of measurement come? They were decided on by men. A "yard" might have originally been the distance from the nose of a certain king to the tip of his outstretched arm. Perhaps a "foot" measured the length of one of the king's feet. But kings' feet come in different sizes, and measurements must be exact. Whether a person tries to fit shirts or to fit automobile tires, he must have exact measurements. A standard unit must be used to avoid confusion.

If a large number of people use the same unit of measurement, the unit becomes a standard unit. Large numbers of people use the inch, the foot, the yard, and the mile to measure length. They use the ounce and the pound to measure weight. They use degrees Fahrenheit to measure temperature. These units are in the **English system** of standard units.

There are more people, however, who use a different system of standard units. They use the **metric system.** They use the centimeter, the meter, and the kilometer to measure length. They use the gram and the kilogram to measure the **mass** of objects—that is, the amount of **matter** in them. And they use degrees Centigrade to measure temperature. Scientists use the metric system. Can you find out why?



Scientists use the metric system because the standards used are known to all and easily reproducible, and because it is easier to calculate numbers in the metric system.

point out that money is a system of measurement also—it measures the value of objects—and the fact that each country has its own monetary system makes trade and travel more confusing and difficult than it might otherwise be. Finally, you can introduce the idea of a universally agreed-upon system of measurement that does away with differences and ends confusion. This system is the metric system, which has been adopted by scientists throughout the world. It is a little-known fact that the standard units used in the United States are, in fact, metric units. By law, the standards of length and mass in the United States are the meter and the kilogram. The commonly used yard and pound are defined in terms of these metric standards.

Follow-Up: To impress on the pupils the inconvenience of the pound as a standard unit of measurement (this is to introduce the convenience of the metric system), you can have the pupils do the following. Manufacturers of packaged foods quite often use odd measures of ounces and pounds. Note the weights and prices marked on food packages and compare them. Pupils will find it difficult to make comparisons among different brands of the same product in terms of cost per unit of weight.

TEACHING SUGGESTIONS
(pp. 6–7)

LESSON: How are objects measured in the metric system?

Background: The prefixes used in the metric system were intended to be a guide to the relative sizes of the units used. All subdivisions of the basic measure are from the Latin; all multiples of the basic measure are from the Greek.

Learnings to Be Developed: There are differences between the English system and the metric system.

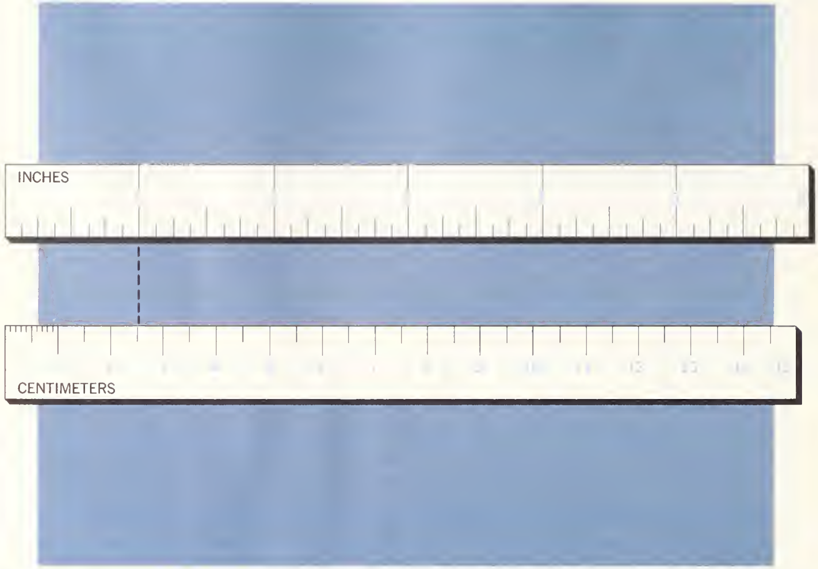
Developing the Lesson: Beginning with what is familiar, review how the pupils measure length using the English system of measurement.

How can a measurement originally made in yards be converted into feet and then into inches?

Depending on how complicated a problem you set for your pupils, many of them are sure to be confused.

Do you have the same trouble changing dollars into cents or making change from a dollar bill?

Point out to the pupils that we use the decimal system in our money. With a few examples on the chalkboard, show how easy it



Changing from One System to Another

Here are two rulers. One looks familiar to you; the other may not. Yet the unfamiliar one is used in almost all non-English-speaking countries. You can use either one, of course, to measure your height. Perhaps you are 58 inches tall, and this fact is noted on your school record for this year. If you were a student in Italy, your school record would say that your height is 147 centimeters. This may sound as if you would be taller in Italy, but remember that the standard units are different from the ones we use. You can change measurements in one standard unit into measurements in another. In the example above, you saw that 58 inches is approximately the same as 147 centimeters.

To make it easier for scientists to understand each other, England decided in 1965 that she will use the metric, rather than the English, system of measurement.

In the metric system, larger units are formed from smaller ones in a series of regular steps. Each unit is ten times the size of the next smaller unit. The names of the units are formed by adding a prefix to the basic unit. In measuring length, the basic unit is the meter. The prefix tells how many meters or how many parts of a meter the unit contains.

Milli is a prefix that means one one-thousandth part of, or 1/1000. *Centi* means one one-hundredth part of, or 1/100. What does *deci* mean? *Deca* means ten and *hecto* means one hundred. What does *kilo* mean?

One meter is equal to 39.37 inches. How many inches are in a *deca*meter? A *hecto*meter? A *kilo*meter? To answer these questions, you must change a measurement in one system of standard units into a measurement in another system. You change units from the metric system into units from the English system.*

The table on the right below shows how to change units from the English system into units from the metric system.

The standard unit of mass in the metric system is the *gram*. A nickel, for example, is an object that has a mass of about 5 grams.

1 *kilo*meter	=	1,000 meters (10 *hecto*meters)
1 *hecto*meter	=	100 meters (10 *deca*meters)
1 *deca*meter	=	10 meters (10 meters)
1 meter	=	1 meter (10 *deci*meters)
1 *deci*meter	=	1/10 meter (10 *centi*meters)
1 *centi*meter	=	1/100 meter (10 *milli*meters)
1 *milli*meter	=	1/1000 meter

English System		*Metric System*
1 inch	=	2.54 centimeters
1 foot	=	0.305 meter
1 yard	=	0.914 meter
1 mile	=	1.61 kilometers

*10 times 39.37 inches in a decameter.
100 times 39.37 inches in a hectometer.
1,000 times 39.37 inches in a kilometer.

is to calculate the value of anything in dollars and cents. Essentially, in the decimal system we can convert from cents to dimes and then to dollars by moving the decimal point. You can then go on to the metric system of measurement. The basis of length is the meter (as the dollar is the basis of our monetary system), and objects in the metric system are either subdivisions of the meter or multiples of the meter. It would be best to write several long numbers on the chalkboard and show how meters are easily divided or multiplied simply by moving the decimal point. Each movement of the decimal point represents the same measurement with a new prefix.

ADDITIONAL ACTIVITIES:

The metric system and its units, are used exclusively in all scientific work and they are being used more and more in everyday life. Have each pupil find out his height in centimeters. (To convert inches into centimeters, multiply the inches by 2.54. To convert centimeters into inches, multiply the centimeters by 0.3937.) Have the pupils then convert their heights from centimeters into meters (that is, move the decimal point two places to the left).

TEACHING SUGGESTIONS
(pp. 8–9)

● **LESSON:** How does temperature influence the length of an object?

Background: The point being made on this page is that there is nothing "natural" about the length of the meter. The meter was originally intended to be a natural measure in the sense that it was based on the circumference of the earth, and this circumference could be measured by a competent surveyor anywhere on earth. As originally defined, the meter was 1/10,000,000 of the distance between the equator and the North Pole. An extremely accurate survey was made of the length of the meridian that passed through Dunkirk, France, and Barcelona, Spain, both of which are at sea level. The survey was made in the middle of the French Revolution and was completed after many difficulties. Once the meter was adopted as a standard unit of length, the circumference of the earth became irrelevant. By international agreement, the length of the meter is the distance between two marks on the bar which is mentioned in the text.

The unit of mass, the kilogram (p. 13), was in turn derived from the weight of pure water con-

Natural Units

The metric system was established in France in the 1790's. Later it was adopted by most other countries. The length of the meter is not based on any object found in nature. It is the distance between two scratches on a platinum bar kept in the International Bureau of Weights and Measures in France. Standards are established in each country, and these standards are compared to the one in France. The gram is the mass of a particular cylinder of platinum that is also located in the International Bureau of Weights and Measures. The meter and the gram are, thus, not natural units. They are units that were decided on by man.

The units that we use to measure the day and the year come close to being natural units. One year is about the time it takes the earth to go around the sun—365 days. One day is the time it takes the earth to rotate once on its axis.

However, there is nothing natural about the way the day is divided. The day is divided into 24 hours. Each hour is divided into 60 minutes. Each minute is divided into 60 seconds. How many seconds are there in one day?* Both the English system and the metric system use the same standard units to measure time.

The cylinder housed under three glass jars is the International Kilogram. Why do you think it is protected in the manner shown above?**

Unchanging Measures

Once standard units have been established, it may seem that all problems of measurement have been solved. This, however, is not true. Do the following experiments to find out what kinds of problems have not been solved.

*There are 86,400 seconds in a day.

**The kilogram is kept under three glass jars to prevent accidental damage, to maintain the same temperature, and to prevent harmful corrosion.

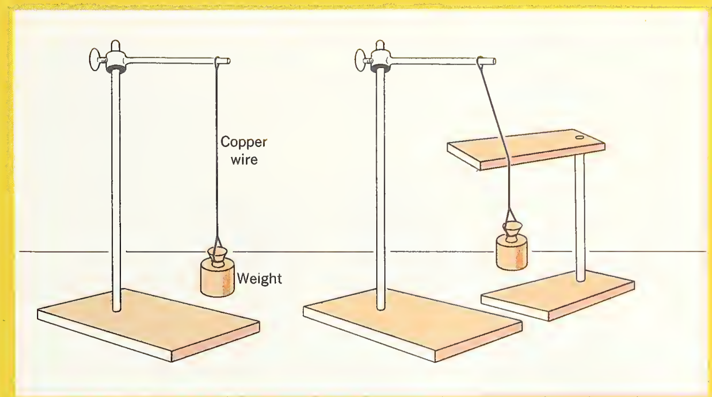
Does the Length of a Wire Change?

What You Will Need

a weight
copper wire
candle or alcohol lamp
ruler

How You Can Find Out

1. Tie the weight to the end of the copper wire.
2. Tie the other end of the wire to a firm support, as shown.
3. Let the weight hang down over a second support.
4. Measure the distance between the weight and the point where the wire curves over the second support.
5. Heat the wire for a minute or two with a candle or an alcohol lamp. Notice what happens to the weight.
6. Measure the distance from the weight to the second support again.



Questions to Think About

1. What happened when the wire was heated?
2. Can you guess why this happened?
3. What does this experiment show?

tained in a vessel that measured exactly 1,000 cubic centimeters.

Learnings to Be Developed: For accurate communication, conditions under which measurements are taken should be reported.

Developing the Lesson: The point of the experiment on page 9 is that the length of an object changes according to the temperature at which it is measured. The simplest way of conducting the experiment is to mark off two points on the wire with daubs of paint or to twist rings of wire around the copper wire at two different points. A pair of dividers can then be adjusted until it measures these points. (In the experiment it is necessary only to show that the copper wire expands, not to measure the amount of the expansion.) After the wire has been heated, the dividers can be laid alongside the marks, and the increase in length between the marks will be self-evident. The wire will expand because of the increased motion of its molecules as it is heated; this motion causes the molecules to push away from each other. The experiment shows the importance of maintaining a constant temperature when measuring a length accurately, or at least of noting the changes in temperature when making a series of comparative measurements.

TEACHING SUGGESTIONS
(p. 10)

LESSON: What influence does temperature have on the volume of a liquid?

Background: The experiments on this page and on page 9 are varieties of the same experiment. On page 9, there was essentially a change in volume in the copper wire, but the diameter of the wire was so small compared with its length that only the change in length was noticeable.

Learnings to Be Developed: The volume of an object increases when the object is heated.

Developing the Lesson: This experiment follows naturally after the experiment described on page 9. Both should be conducted on the same day, if possible.

The procedure for the experiment is self-evident. The effect of the experiment can be enhanced if a bottle, a one-holed stopper, and a length of glass tubing are obtained from the chemistry lab. The tubing is inserted into the stopper, which is then inserted into the filled bottle of water. The water will rise into the glass tubing. The effectiveness of the experiment is thus much increased.

EXPERIMENT

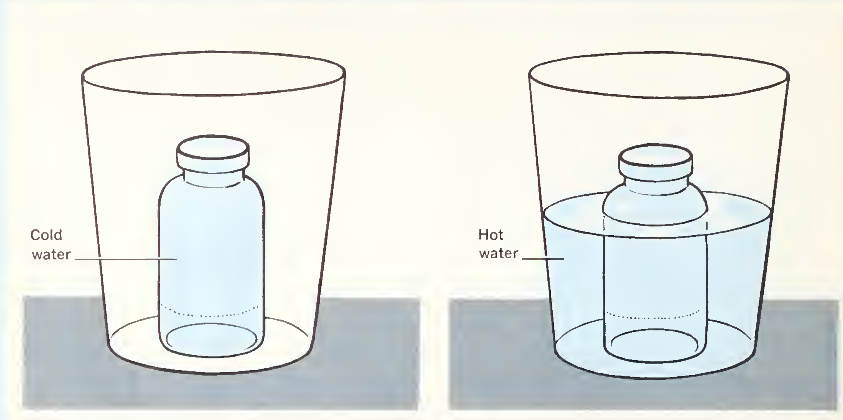
Can the Amount of Space Occupied by a Liquid Change?

What You Will Need

pail   narrow-necked quart jar   water

How You Can Find Out

1. Put a narrow-necked jar in a pail.
2. Fill the jar to the very brim with cold water.
3. Put enough hot water in the pail to go about three-quarters of the way up the outside of the jar.



Questions to Think About

1. What happens to the water in the jar?
2. Can you guess why this happened?
3. What does this experiment show?

First the water took up one quart of space. After it was warmed, it took up more than one quart of space. The amount of space something occupies is its **volume.** The volume of water changed when the temperature changed.

Gravity and Weight

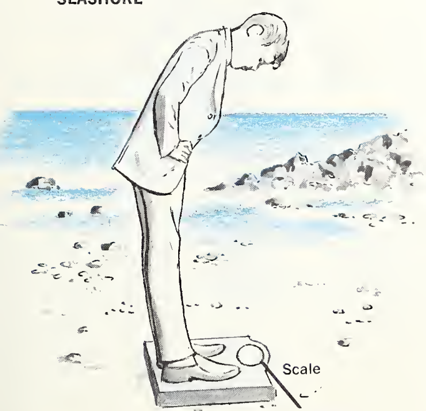
The level of the surface of the sea is referred to as **sea level.** You weigh a certain amount at sea level. If you were on the top of a high mountain, you would weigh slightly less than you do at sea level.

Why does your weight change? The answer is that your weight depends on the *attraction* between you and the earth. **Gravity** is the *pull* toward the center of the earth. The closer you are to the center of the earth, the greater the pull. The farther away you go, the weaker the pull! You weigh more on a bathroom scale when there is a greater pull. You weigh more in a deep mine because you are closer to the center of the earth, and the pull on you is greater. You weigh less on a high mountain because you are farther from the earth's center than you are at sea level. Where do you think a man would weigh more, in an airplane or in a submarine? Why?

The length, volume, and weight of objects are not always the same. They depend on other things, such as temperature and distance from the center of the earth.

When scientists measure, they use the standard units of measurement, and they measure everything under the same conditions.

SEASHORE



ABOVE SEA LEVEL

TEACHING SUGGESTIONS

(p. 11)

LESSON: How does the weight of an object change as its distance from the center of the earth changes?

Background: The main point about gravity insofar as scientific measurement is concerned is its inconstancy. Gravity is only an effect—the effect of two masses acting upon each other through a certain distance. What is more important is the mass of a body. This concept is introduced on the next page.

Learnings to Be Developed: The weight of an object is not constant, but changes with changes in altitude. Therefore the weight of an object must be stated in terms of its position.

Developing the Lesson: This is a topic that is difficult to develop in terms of the pupil's own experiences. Probably the simplest and best way of proceeding is by giving a short lecture on the force of gravity and how the influence of this force decreases as objects travel away from the center of the earth. The main point to be developed is that the effect of gravity on an object is to give it that quality which we call "weight," and that any changes in this force cause "weight" to change.

TEACHING SUGGESTIONS
(pp. 12–13)

LESSON: What is the mass of an object?

Background: Objects will behave in outer space as they do on earth by virtue of their inertial mass, which remains the same.

Learnings to Be Developed:

All objects have mass.

Mass is the amount of matter in an object.

Developing the Lesson: The concept of mass can be developed by giving examples of how mass and weight differ from each other. One example is to ask the pupils to imagine a bowling ball and a marble on the surface of the earth. They both have weight—the bowling ball much more than the marble—caused by the pull of gravity.

- *What would happen to the bowling ball and the marble if they were in outer space?* (They would both be weightless.)
- *Does this mean that the bowling ball could be pushed around as easily as the marble could?* (Not at all. If, in outer space, you could throw the marble at the ball, the ball would not budge, because its mass would not have changed. On the other hand, if you were to hit the marble with the bowling ball, the marble would travel a long distance.)

Matter and Mass

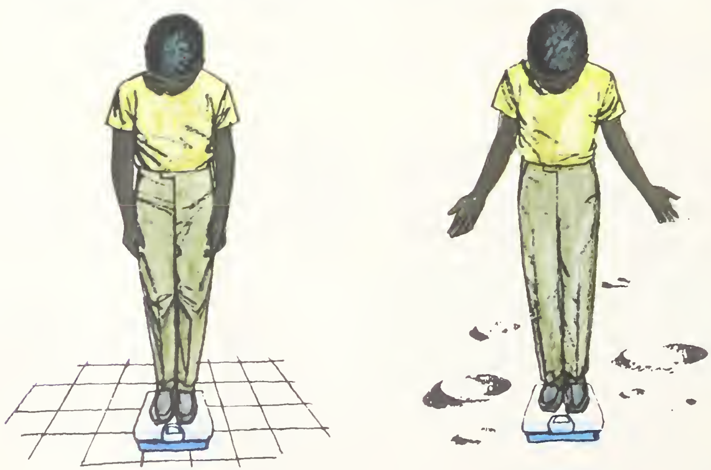
Sometimes a scientist wants to measure how much material, or matter, makes up an object. What unit of measurement can he use? He cannot use length, because, as you saw in your experiment with the copper wire, the length of some objects changes when the temperature changes. He cannot use volume, because, as you saw when you experimented with water, the volume of water changes when the temperature changes. He cannot use weight, since the weight of an object changes according to how high up it is.

What unit of measurement can the scientist use? Scientists have solved this problem by using the unit of measure called *mass*. Mass is the amount of matter in an object.

Although your weight depends on where you are standing, you are still you! You have the same arms, the same legs, the same head, and the same body on the top of the mountain as you do at the bottom. The weight of your body has changed, but your body has not.

Think about an astronaut in space. The farther away he is from the earth,

Would you weigh the same on earth as you would on the moon? Would you have the same mass? How do weight and mass differ? Can you tell if your mass ever changes?



the less he weighs. He is still, however, the same astronaut. The reason he weighs less is not that he took off his space suit and not that he suddenly got thinner. He weighs less because he is farther from the center of the earth. But although his weight has changed, his mass has *not* changed. Remember that mass is the quantity of matter in an object. What the astronaut is made up of, his mass, has not changed. All that has changed is the attraction between him and the earth.

Scientists use mass as a unit of measurement because it does not depend on where measurement is made.

In order to make sure that a measurement is accurate, there has to be something with which to compare that measurement. The mass of a kilogram is that of a platinum cylinder also located in France.

Relationships

It is often possible to solve a problem about measuring by finding only one quantity. For example, you might want to find the distance from one end of your classroom to the other. You might want to measure the time it takes to go from one place to another. Or you might want to find out how fast a car is going.

Instruments help you to solve such problems. What instrument would you use to measure the length of your classroom? What instrument would you use to measure the time it takes to go from one place to another? What instrument tells you how fast a car is going?

However, there are many problems in science that can be solved only if you know how distance, time, and speed are related. For example, most people can walk about 3 miles in 1 hour. Suppose that you were told that Harry walked from Centerville to Pine Ridge in 4 hours. Suppose that you were then asked, "Did Harry walk faster or slower than most people?" You could not answer this question unless you knew another quantity—the distance between the two towns. If you knew that the towns were 8 miles apart and that it took Harry 4 hours to make the trip, would you say he was a fast walker?

To solve this problem, the first thing you want to know is how many miles an hour Harry walks. You want to know this so that you can compare it to how many miles an hour most people walk. The first step is to divide the distance (8 miles) by the time it took Harry (4 hours) to walk the distance.

$$\frac{8 \text{ miles}}{4 \text{ hours}} = 2 \text{ miles an hour}$$

TEACHING SUGGESTIONS
(pp. 13–16)

LESSON: What is the relationship between the distance from one place to another, the speed at which an object travels, and the time it takes for the object to travel from one place to the other?

Background: The pupils are being introduced to the concepts of distance, speed, and time (especially speed). The problems in the text are designed to make the relationship among these quantities clear. The pupils are also being introduced to the idea of combining measurements that, so far, they have considered separately. The speed of an object is, after all, the combination of the measurements of time and distance.

The pupils already possess an intuitive knowledge of both distance and time, and very little time need be taken up in discussing these quantities. The main emphasis in the classroom should be on teaching that the measurement of speed depends on the measurement of two other quantities—distance and time. The subject matter of pages 13 through 20 can, in fact, be summarized by three formulas:

speed = distance ÷ time
distance = time × speed
time = distance ÷ speed

Learnings to Be Developed:

Measurements such as speed can be derived from other basic units.

The measurement of the speed of a moving object is the ratio between the distance traveled over the time taken.

Developing the Lesson: The material from page 13 through the beginning of page 16 can be assigned for home reading before the subject is discussed in class. In class, the concept of speed can be developed by asking questions.

- *Suppose your family car didn't have a speedometer. Could you tell how fast the car was going at any one instant? Could you figure* average *speed for a trip? How?*

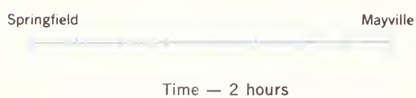
In your questions, emphasize the point that *both* distance and time must be known before an object's speed can be calculated. Once the relationship between distance and time has been understood, write the formula on the chalkboard to show how easily one can learn the speed of a moving object by solving a simple mathematical equation. By manipulating the quantities of distance, time, and speed in formulas, the pupils can learn how intimate is the connection between these quantities.

The next step is to compare. Since you know that most people walk 3 miles an hour, you now know that Harry walks slower than most people.

Because you knew the distance between the two places and the time it took Harry to walk that distance, you could find his *speed*. Speed is the time it takes to go a certain distance. Suppose that the distance between Paul's house and Paul's school is 4 miles. It takes him 1 hour to walk to school. How fast is Paul walking? You can easily determine that the speed at which he is walking is 4 miles an hour.

Can you solve these two problems?

1. The distance between Springfield and Mayville is 80 miles. A car travels 2 hours to go from Springfield to Mayville. What is the speed of the car? Here is a picture of the problem.



2. The air distance between New York City and San Francisco, California, is about 2,500 miles. A jet airplane takes about 5½ hours to fly this distance. How fast does the plane travel? Can you make a picture of this problem?

To find the answers to these problems, you divided the distance by the time. To explain how you solved these problems, you might say, "If you want to find the speed, divide the distance by the time." Or:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

This way of writing what you mean is called a **formula.** A formula explains ideas in a shorter way.

You have used formulas before. If you wanted to say that 300 added to 300 is 600, you wrote:

$$300 + 300 = 600$$

If you wanted to say that 300 multiplied by 2 is 600, you wrote:

$$300 \times 2 = 600$$

If you wanted to say that half of 600 is 300, you wrote:

$$\frac{600}{2} = 300$$

These are different ways of showing the same relationship. You can show the same relationship in different ways with distance, speed, and time also. You can say that if it takes a plane 2

hours to fly 600 miles, then the plane is flying at a speed of 300 miles an hour:

$$\frac{600 \text{ miles}}{2 \text{ hours}} = 300 \text{ miles per hour}$$

You can say that if the speed of an airplane is 300 miles an hour and it traveled for 2 hours, the distance it traveled was 600 miles. You would write:

$$300 \text{ miles per hour} \times 2 \text{ hours} = 600 \text{ miles}$$

Both statements say the same thing. If you can say that

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

then you can also say that

$$\text{distance} = \text{speed} \times \text{time}$$

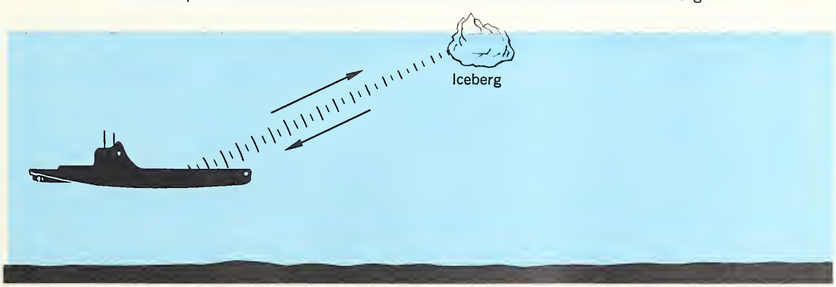
Can you find a third way of showing this relationship? How is time related to the other two quantities? Finish this statement on a separate piece of paper:

$$\text{time} = \frac{?}{?}$$

Using Relationships

We use the formulas that tell how to find distance, speed, and time in very important ways. Suppose you were on an atomic submarine and wanted to measure the distance from the submarine to an iceberg. It is easy to see that this distance cannot be measured with a yardstick. But you can use one of the formulas. You know the speed of sound. Sound travels about ⅘ mile in one second in water. You can send out a sound to the iceberg. When the sound reaches the iceberg, it bounces back as an echo. You can time how long it takes the sound to go to the iceberg and come back to the submarine. There is an instrument called **sonar** (SOH-nahr)

Use the picture to tell how sound is used to find the distance to an iceberg.



○ **ADDITIONAL ACTIVITIES:**

Without being consciously aware of it, the pupils undoubtedly appreciate that relationships exist between many of the things with which they are familiar. It would be interesting to have them explore these relationships without trying to develop them into formulas. For example, there is a relationship between the time it takes to empty a bathtub and the size of the drain. There is a relationship between the brightness of a lamp and the number of watts it is rated at. There is a relationship between the temperature of the air and the number of hours of sunlight.

On page 16, graphs are introduced, and these examples are an excellent way to plant the ideas that are made visible in the lines of a graph.

TEACHING SUGGESTIONS
(pp. 16–19)

LESSON: How are graphs made and used?

Learnings to Be Developed: Graphs enable us to see various kinds of relationships.

Developing the Lesson: Before the information on pages 16 through 19 is discussed in class, these pages can be assigned for home reading. One way to introduce this subject in class is to announce beforehand that your pupils are going to learn how to construct graphs of speed, time, and distance. The graphs will represent the equations (formulas) they learned about on pages 13 through 16. A graph is another way of presenting the facts in a formula. You can then proceed to draw a graph resembling the illustration on the top of page 17. The pupils undoubtedly are familiar with the use of graphs in advertising, and in newspaper and magazine articles they may have read, but it is important that you assume nothing and explain as carefully as you can that each vertical and horizontal line represents the same quantity over the entire length of the line, that the lines are evenly spaced so that relative increases in speed and distance are accurately shown, and that the point where two lines meet represents a third quantity. Having completed the

on a submarine. Sonar measures how long it takes the sound to make the round trip to the iceberg. By using sonar, you can find that it takes 20 seconds for the round trip. Now you know two quantities—speed and time.

Here is the formula to use:

$$\text{distance} = \text{speed} \times \text{time}$$

You multiply the speed of sound ($\frac{4}{5}$ mile a second) by the time it takes the sound to go out and come back (20 seconds).

$$\text{distance} = \text{speed} \times \text{time}$$
$$\text{distance} = \tfrac{4}{5} \times 20$$
$$\text{distance} = 16 \text{ miles}$$

But the problem is still not solved. It is 16 miles for a round trip, and you want to know how far away the iceberg is, or how far the sound has to go one way to reach the iceberg. How can you find the answer?

Making Graphs

Once you know how to draw and how to read a graph, you can see many relationships at a glance. A graph can show how distance, time, and speed are related. A graph is very helpful, because it saves time. Instead of having to read many pages of facts, we can see them all on one graph.

Drawing the Graph

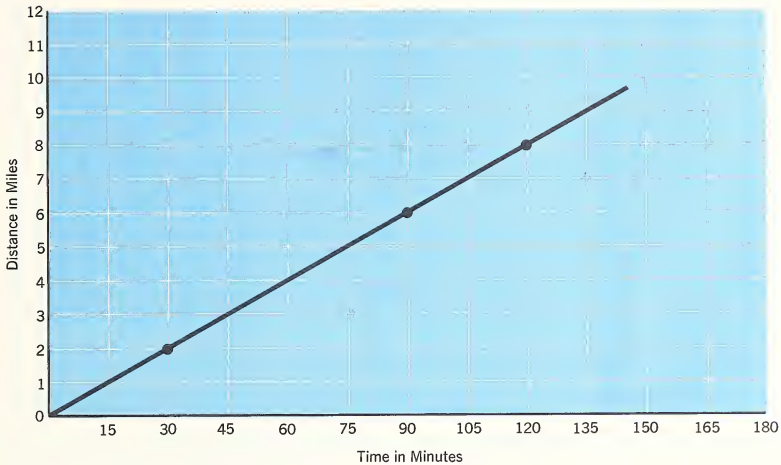
The first thing you need to draw a graph is paper that is divided into many small boxes. You can use the horizontal lines to represent one quantity and the vertical lines to represent another. Look at the graph. The bottom horizontal line is labeled "Time in Minutes" and represents 180 minutes. Each division of the line stands for 15 minutes. If you move one unit along the horizontal line, you have represented 15 minutes. The vertical line is labeled "Distance in Miles" and represents 12 miles. Each division stands for 1 mile. If you move one unit up the vertical line, you have represented a distance of one mile.

The graph you looked at shows the relationship between the distance that Henry walks and the time it takes him to walk it. You draw, or *plot*, the graph by putting in the information you have.

Suppose you know that:

1. At the end of 30 minutes, Henry walked 2 miles.
2. At the end of 90 minutes Henry walked 6 miles.
3. At the end of 120 minutes, Henry walked 8 miles.

The first thing to do is to find the spot that stands for 30 minutes. Since



the horizontal line stands for time in minutes, you would look along this line. Start at 0 and move across the line until you come to the line that stands for 30 minutes. Put your pencil on this line. Since the vertical line stands for distance, you have to move your pencil up the 30-minute line until you come to the line that stands for 2 miles. Put your first dot here. Check the graph to see if you found the right spot.

To find where the second dot goes, do the same thing that you did for the first dot. Find the line that stands for 90 minutes, move up the line until you come to the line that stands for 6 miles, and put the dot there. Check the graph to see if you found the right spot.

Plot the third dot in the same way. Now draw a line that connects the three dots. The graph is finished.

Reading a Graph

Now that you know how to plot a graph, it will be easy for you to learn how to read it. If you know that Henry walked for 30 minutes, can you tell how far he walked? Put your pencil on the line that stands for 30 minutes and move up that line until you find the spot where the graph touches that line. You see that it touches at 2 miles. Henry walked 2 miles. Now answer the questions on the next page.

graph, you can use it to solve the problem given on page 16. Although a curve has been drawn on the graph, the problem states only that at the end of three different time intervals, Henry had walked certain distances. Be sure that you place only these three points on the graph. You might then recapitulate the information given on pages 13 through 16 to show that the formula

speed = distance ÷ time

with the correct data inserted shows that the speed at which Henry walked is 4 miles per hour. Since the graph shows that Henry walked at the same average speed over a period of 120 minutes, it seems reasonable to suppose that he was walking at that speed—4 miles per hour —at all the unmarked intervals between the three marked points on the graph. You can then draw a line through the three points on the graph to show that he walked at a steady speed.

Point out that the graph can show many things one would not know without it. Now the pupils can tell at a glance how far Henry has walked after 15 minutes, after 60 minutes, etc. The straight line represents a constant speed of 4 miles per hour, and you can mark the line on the chalkboard. It will now be a simple matter to introduce

Warren, who is walking at a slower rate, and plot the information given for him on page 18. Warren is walking at the rate of $1\frac{1}{3}$ miles per hour.

ADDITIONAL ACTIVITIES:

You can reinforce the pupil's knowledge of the English and metric systems of measurement very simply by showing how the axes of the graph can be marked off in different scales that will represent the same things. The horizontal scale can again be marked off in "Time in Minutes," and the vertical scale can be marked off in "Distance in Meters." The pupils can then see how easy it is to read off how fast Henry and Warren are traveling in meters per minute, meters per hour, etc.

Construct a graph that does not have a straight line curve. The horizontal could represent days and the vertical could represent temperatures over the past week. Discuss how this information is useful to meteorologists.

Plot graphs of the temperature variations over a period of one school day.

Plot graphs for the growth rate of three or four window plants over a period of a week or two.

1. How far did Henry walk in 90 minutes?
2. How far did Henry walk in 120 minutes?
3. How far did Henry walk in 135 minutes?

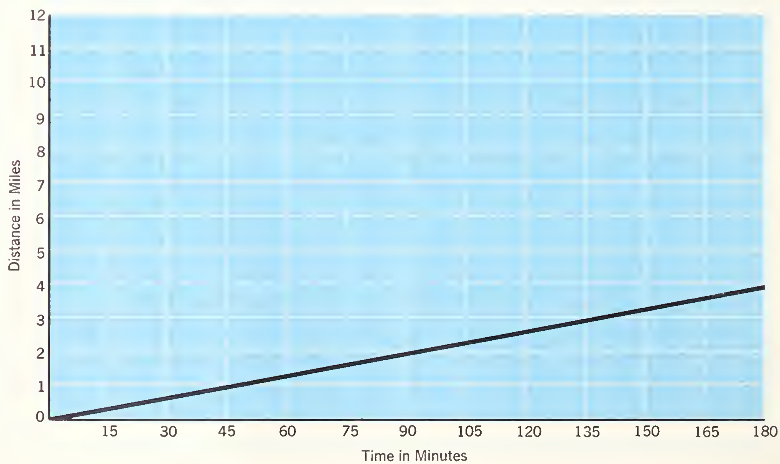
Suppose you knew that Henry walked 2 miles and you wanted to know how long it took him. You would put your pencil on the line that stands for 2 miles and move across it until you found the spot where the graph touches that line. You would see that it touches at 30 minutes. Therefore, it took Henry 30 minutes to walk 2 miles. If Henry continued at the same rate:

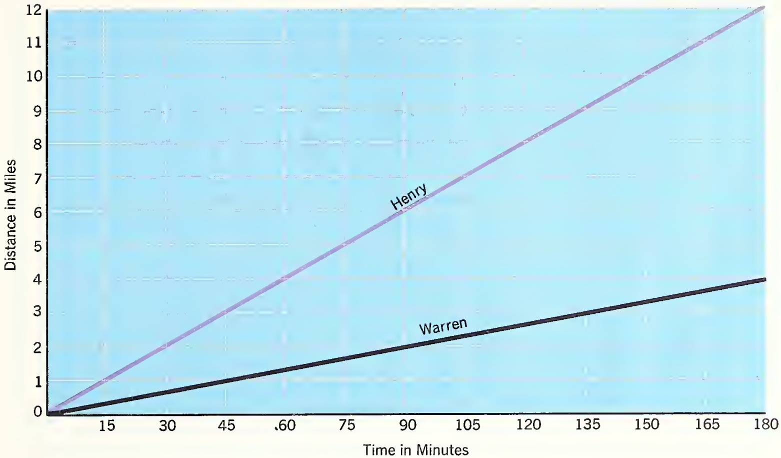
1. How long would it take Henry to walk 6 miles?
2. How long would it take Henry to walk 7 miles?
3. How long would it take Henry to walk 10 miles?

The graph that you see at the bottom of this page shows the relationship between time and distance for Warren's walk.

Use the graph to answer these questions:

1. How many minutes did it take Warren to walk 1 mile?
2. How many minutes did it take him to walk 3 miles?
3. How far did Warren walk in 90 minutes?
4. How far did he walk in 3 hours, or 180 minutes?





Look at the graph above. This time the two walks are shown on the same graph. Use it to answer these questions:

1. When Henry had walked 3 miles, how far had Warren walked?
2. When Henry had walked 9 miles, how far had Warren walked?
3. How far had each boy walked in 60 minutes?
4. Which boy walked faster?

Whenever you talk about the relationship between distance and time, you are talking about speed.

The red and green lines on this graph tell about relationships between distance and time for Henry and Warren. They must, then, tell us something about the speed of each boy. You can use the formula

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

to find how fast they walked.

The graph tells you something else. Notice that Henry's line is steeper than Warren's. Remember, Henry is walking faster. That means he is covering more distance than Warren in the same time. To find out where to put your dot for Henry's position at the end of a certain time, you had to go up higher on the vertical line than you did for Warren. If you go *over* the same distance but *up* farther to put your dots, then your line will be steeper. A steeper line shows a higher speed.

TEACHING SUGGESTIONS
(p. 20)

LESSON: In what other ways can graphs be used?

Learnings to Be Developed: Graphs can be used to show many different types of relationships.

Developing the Lesson: Page 20 can be assigned as homework. Each pupil should have a sufficient quantity of ruled graph paper (the larger the squares, the simpler it will be for them to mark off the points on the graph) to enable them to complete the assignment. You can then go over the problems in class to ensure that the pupils have understood the problems and to review pages 13 through 19.

TEACHING SUGGESTIONS
(p. 20)

Background: The steepness with which a curve rises as it travels from left to right is known as its *slope*. The steepness of the slope is an indication of the comparative *rate* of change. That is, Henry and Warren (pp. 16–19) are walking at certain rates of speed, and the car discussed in problem 1 on this page uses up gasoline at a certain rate. The rates of change are constant, however.

Problem 2 on this page introduces a new quantity — *acceleration*, — which is a change in the rate at which an object is moving. Notice that the axes of the graph are to be marked as *speed* and *time*, not *distance* and *time* as in the previous problems. Since it is the speed that is changing, the curve now shows changes in acceleration.

In problem 3, if the automobile is traveling at a constant speed, there is no acceleration, and the line will be perfectly horizontal. This will be more obvious if a table is made that shows the speed at different times. No matter how much time has passed, the automobile will still be going at the same speed.

Using What You Have Learned

1. Graphs show relationships of quantities other than time and distance. The graph explained below shows the relationship between the amount of fuel in a car tank and time.

A man is driving his car across the desert at a steady speed. He began with a full tank of 16 gallons of gasoline. He uses up 1 gallon of gas every 20 minutes.

Plot a graph to show this relationship. Write the numbers from 1 to 16 along the vertical edge of the graph paper. These numbers stand for the amount of fuel in gallons. Along the horizontal edge, write the numbers 20, 40, 60, 80, and so on until there are 16 numbers. These numbers stand for minutes. You know that the man uses up 1 gallon of gas every 20 minutes. Where would you put the dots to show how much gasoline he used up in 20 minutes, in 40 minutes, and in 60 minutes? Now draw a line to connect the dots. Can you find out by reading this graph how much gasoline the man used in an hour and a half?

2. Moving objects do not always travel at the same speed; they may speed up or slow down. When an object changes its speed, we say that it **accelerates** (ak-SEL-er-ayts).

You can draw a graph to show acceleration, or how speed changes with time. Put *speed* along the vertical edge, and *time* along the horizontal edge.

At the start the car is motionless. After 5 seconds it is going 10 miles an hour. After 10 seconds it is going 20 miles an hour. After 20 seconds it is going 40 miles an hour. It keeps accelerating at the same rate. How fast is it going after 15 seconds? After 35 seconds? How long does it take for the car to accelerate to 60 miles an hour?

3. What would the speed line look like on a speed-time graph if the speed were steady? Prove it.

What to Measure?

Throughout the history of science, measurements have been used to help men explain and develop their ideas. In fact, almost every scientific idea is a result of new measurements or a result of using known measurements in new ways. You will now read the stories of three important discoveries and how they were made with the help of measurements.

Lavoisier and Chemical Reactions

Before 1800 it was thought that when a substance burned it lost something. After wood is heated or burned, it weighs less. When cloth is heated, it loses weight. Chemists of long ago said that if a substance loses weight when it is burned, then something must be released into the air. All ideas of what happened in a chemical reaction were based on this belief.

But chemists began to use more accurate balances, or scales, to measure mass, and they discovered new facts. With these new balances, scientists learned that when mercury, zinc, or copper is heated, it *gains* weight. This fact did not fit the old ideas. If a substance that remains in the same place gains weight, it must have more mass. The additional mass must somehow come *from* the air. What substance in the air is added to heated mercury, zinc, or copper?*

These new measurements and observations were important to the French chemist Antoine Lavoisier (an-TWAHN lah-vwah-zee-AY). They led him to search for the substance that was removed from the air when something was burned or heated. After many experiments and very careful measurements, he found that the substance was a gas that he called oxygen. His discovery of oxygen led chemists to turn from one idea about chemical reactions to another. They now believe that when something burns it takes some oxygen from the air.

Without careful measurements and the knowledge of what the measurements meant, chemistry would not have changed as it did in the late 1700's.

** The substance in the air that is added to heated mercury, zinc, or copper is oxygen. These substances become oxides.*

This picture made in 1575 shows 16 men standing toe to heel. The length of the line was given the value of 16 feet and was then divided into 16 equal parts. Can you tell why this was done?

TEACHING SUGGESTIONS
(pp. 21–23)

LESSON: Why is it important to take accurate measurements?

Background: The main point being made in pages 21 through 23 and in the biography of Bessel on pages 24–25 is that advances in science have come about when scientists have become able to measure phenomena with greater exactness, thereby becoming aware of discrepancies or facts of which they had been ignorant before. Scientists do not make accurate measurements just to be accurate, but because increased precision of measurement may point out new and unsuspected relationships. And even after increased precision of measurement has revealed discrepancies or new relationships, it may take a genius on the order of Lavoisier or Galileo to appreciate the significance of the measurements.

Learnings to Be Developed:

It is important to be as accurate as possible when taking measurements.

Many scientific discoveries have resulted from comparisons based on accurate measurements.

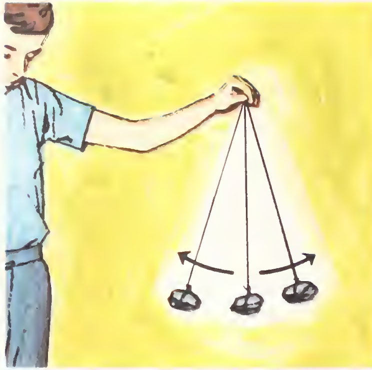
Developing the Lesson: Pages 21 through 25 can be assigned for reading at home. In class, enable

your pupils to develop an awareness of the importance of accuracy in the discovery of new facts. This can be done by asking the pupils questions relating to the importance of measurement in the discoveries of Lavoisier, Galileo, Leverrier, and Bessel.

ADDITIONAL ACTIVITIES:

You may want to read how Inhelder and Piaget have used a pendulum task to study how the pupil goes about separating out factors to determine their related effects and excluding those that do not play a causal role. The factors that the pupil *might* think are relevant are; length of string, weight of object on the string, height of the dropping point, force of the push given by the pupil. Only the first is actually relevant. The pendulum task is well suited to development of propositional or abstract thinking, as pupils test out one proposition at a time. See *The Growth of Logical Thinking from Childhood to Adolescence*, by Inhelder and Piaget, Basic Books. 1958, pp. 67-79.

The pupils might try filling empty tin cans of the same size with different quantities of water. (Double the quantity equals double the weight.) Have them conduct a series of experiments in which, first, the volumes of water in the cans (i.e., the weights) are different and the lengths of the strings are the same, and, second, experi-



Galileo and the Swinging Stone

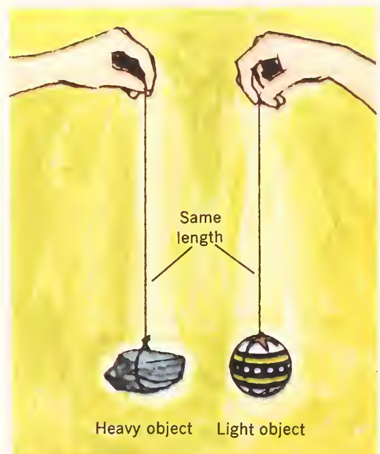
Tie a small stone, or any other small, heavy object, to the end of a string. Start it swinging as in the picture.

Scholars and teachers in ancient times studied this simple movement carefully many times. To them, the most interesting thing about this movement was that the stone finally stopped swinging. When it stopped, it hung straight down. Scholars of ancient times said that any heavy object went from a high position to a low one because it was the nature of heavy objects to do that. The ancient scientists wanted to know how long it took for the stone to hang straight down. They made measurements to find the answer.

Galileo looked at the swinging stone in an entirely different way. He wanted to know whether the time it took for heavy objects to swing from the lowest point back to the lowest point in the swing was the same as the time for light objects. He made many measurements.

He took two strings of the same length. He tied a heavy object to one string and a light object to the other. Then he started both objects swinging and measured the time for each swing. He compared his measurements. Try it yourself. What do you discover? *

Galileo's experiments with the swinging stone, the pendulum, helped change man's idea of how objects move. His experiments helped to establish a new



*Objects of different masses hung from strings of the same length will have the same period.

science of motion. His experiments also showed the importance of measurement in comparing things.

Can you think of anything else about the swinging weight that might be interesting to measure?

Herschel and a New Planet

In 1781 the German-British astronomer William Herschel (HER-shul) discovered the planet Uranus. For many years, other astronomers took many measurements of Uranus' position in order to determine its orbit. The measurements showed some very unusual things about the orbit.

Astronomers thought that the gravitational force of some unknown object in the solar system was causing the peculiar orbit. In 1846 the French astronomer Urbain Leverrier (er-BAN leh-vehr-ee-AY) determined just where this object *should be*. Soon afterward a new planet, Neptune, was found in that spot. Tell about the importance of measurement in finding Neptune.*

Using What You Have Learned

1. Get two balls, a light one and a heavy one. Hold the light one up high. Now figure out where the heavy one must be held so that both balls strike the ground at the same time when they are released at the same instant. Measure the difference in the heights of the two balls. Drop them. What happens? Why?

2. Roll a heavy, solid ball, like a croquet ball, down a slide. Roll a light, solid one, like a rubber ball, down the slide. Do they take the same time to reach the ground? What measurements can you make to find out?

3. Read about how Lavoisier discovered oxygen. Make a report to the class telling what materials he used and what measurements he made.

4. Read about the motion experiments of Galileo. Perhaps you can demonstrate one of his other experiments to the class.

*The importance of measurement in the finding of Neptune was that it took extremely accurate measurement to discover the discrepancies in the orbit of Uranus in the first place.

ments in which the volumes of water are equal but the lengths of the strings are different. Can the pupils discover by themselves that it is the length of the string that determines the period of swing and not the weight? Do not let the arcs of the swings become too large; a 10° arc is sufficient.

TEACHING SUGGESTIONS
(p. 23)

Background: In *Using What You Have Learned* on this page, #1 is a repetition of Galileo's famous experiment in which he dropped weights from the leaning tower of Pisa. The pupils will discover that both balls must be held at about the same height in order to hit the floor at the same time.

In problem 2, the simplest way of making a comparison of the speeds of the two balls is to have them start down the slide at the same moment. Then it will be obvious to the eye whether one rolls faster than the other. The heavier ball should roll down slightly faster. However, to emphasize the importance of accurate measurement, time several rolls of each ball with a stop watch first. Rolling the two balls together can then serve as visual proof of the accuracy of the pupils' measurements.

TEACHING SUGGESTIONS
(pp. 24–25)

Background: Friedrich Wilhelm Bessel was a pivotal figure in the history of astronomy. Before his discoveries, astronomers spent most of their time studying the motions of the solar system; after his discoveries, astronomers became interested in the universe beyond the solar system.

At 20 Bessel recalculated the orbit of Halley's comet. This self-imposed task resulted in his being given a post at a Prussian observatory. When he was 26 he was asked by the King of Prussia, Frederick William III, to superintend the construction of a new observatory at Koenigsberg. He became director of the observatory when it was completed and remained there the rest of his life.

One of the primary tasks of astronomers has always been to map the heavens—to locate as accurately as possible the positions of the stars and to publish star catalogues in which these positions are listed. Bessel noticed that a comparatively dim star, 61 Cygni, had an apparently large *proper motion*. That is, it appeared to have changed its position markedly over the course of a century. By comparing its position very carefully with that of stars near to it, Bessel

PATHFINDERS IN SCIENCE

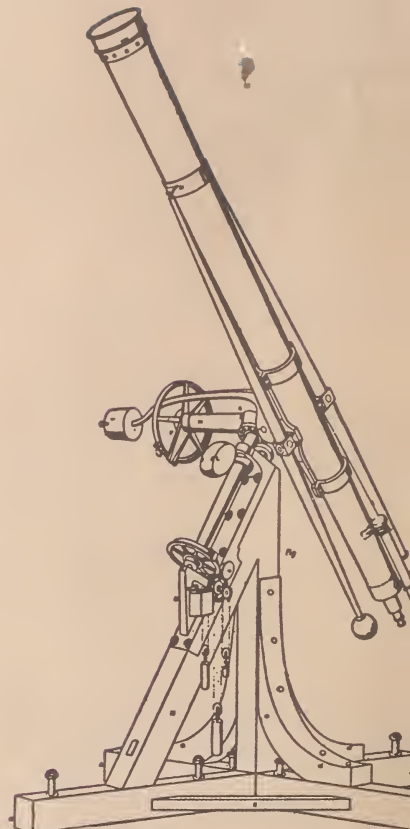
Friedrich Wilhelm Bessel

(1784–1864) Germany

For thousands of years, men looked at the stars and believed them to be much too far away for anyone to measure their distance from the earth.

To see why this was believed, do the following. Hold your finger at arm's length in front of you and line it up with an object in the far distance. Now, without moving your finger, look in the far distance with your other eye. (Use your other hand to cover one eye at a time.) Your finger will appear to jump to one side against the fixed background. If you move your hand rapidly back and forth, covering first one eye and then the other, your finger will appear to jump rapidly from side to side.

This effect is called *parallax*. The farther away an object is, the less the parallax: that is, the less it will appear to jump against its background. You can experiment with objects around you to see that this is so. It is difficult to measure the distance of far objects accurately with your eyes because your eyes are too close together. By using rangefinders, which increase the distance between your eyes artificially, the parallax is increased



and distant objects can be measured accurately.

It was because astronomers could not discover any parallax among the stars, no matter what instruments they used, that they believed the distances of the stars were too great ever to be measured. It was not until a German astronomer, Friedrich Wilhelm Bessel, discovered a way of making the closer stars appear to shift from side to side—as your finger did—that their distance could be measured.

Bessel's father had wanted him to become a businessman, and the young man had studied to be an accountant. But Bessel was much more interested in the stars, so he secretly studied astronomy in his spare time. When he was twenty years old, he figured the orbit of Halley's comet and sent the result to a famous astronomer. The astronomer was so impressed that he found Bessel a position in an observatory.

Bessel became interested in the distance of the stars. He decided the distance could be measured in the following way. As his two "eyes" he used the position of the earth in space as it revolved around the sun. Every six months, the earth has changed its position by 184 million miles as it moves in a great circle around the sun. By measuring the position of a star, called 61 Cygni (SIG-nee), very accurately among surrounding stars and then waiting six months before measuring the position of the star again, Bessel was able to show that 61 Cygni had shifted a very small amount against the background of stars. From the amount of this shift he was able to calculate that 61 Cygni was 35 *trillion* miles from the earth.

Bessel's discovery made possible the direct measurement of distances to the nearer stars.

was able to show by its shift in parallax that 61 Cygni was about 35 trillion miles from the earth, or about six light-years.

Bessel's discovery provided the first direct proof that the Copernican theory of the solar system was the correct one. If the earth didn't move, Bessel would not have been able to discover the displacement of 61 Cygni. This point can be brought out when the Copernican and the Ptolemaic theories are discussed in the unit on Astronomy.

Bessel also discovered that distant stars often have companions and that these pairs of stars orbit around each other. These pairs of stars are called "binary stars," and there are thousands of them in the observable universe.

The techniques worked out by Bessel to measure the position of stars and to analyze their motions are in use today, the chief difference being that photographic plates rather than visual sightings record the stars' positions.

Although the distances of stars can be found indirectly by measuring their brightness or by finding the shifts in their spectra, these other techniques are still anchored to direct measurements made of shifts in parallax, as first done by Bessel.

TEACHING SUGGESTIONS
(pp. 26–27)

LESSON: How is the direction of motion measured?

Background: The purpose of this section is to introduce the idea of a *vector* to the pupils. A vector is defined as a quantity that has both size and direction, or a line representing such a quantity. The pupils will learn how to measure vectors and add vectors together.

Pupils may not appreciate the importance of vectors in the study of physics. In the elementary form in which they are discussed here, vectors are most useful in calculating the effect of two different forces acting upon the same object. Practically, vectors are used to calculate navigation problems for both ships and aircraft, and perhaps the interest of the pupils can best be aroused by working out simple problems in which aircraft or ships travel from one point to another.

Learnings to Be Developed:

To describe motion accurately, one must know not only the speed but also the direction of motion.

There is a difference between the speed of an object and its velocity.

Developing the Lesson: Begin by reviewing the contents of pages 26 through 29 to make sure that the

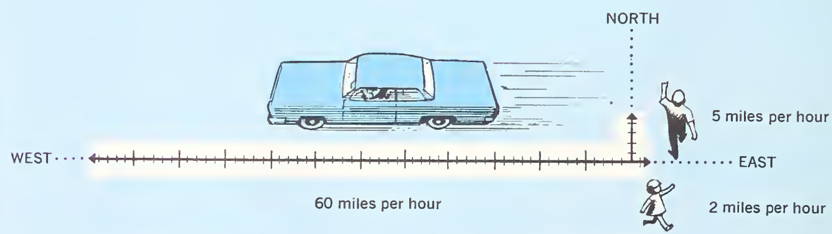
How Much Information?

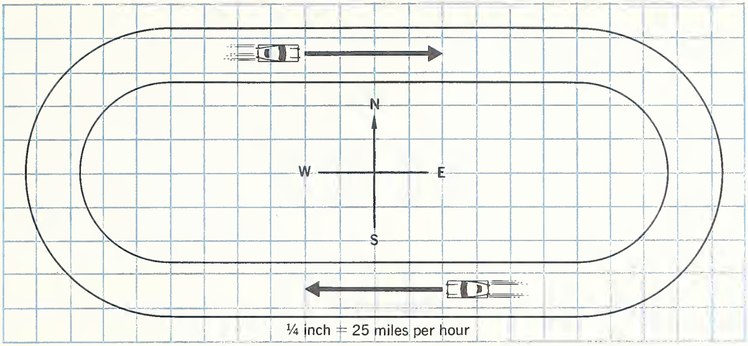
Two boys start running from the same spot. Bob runs 11 miles per hour. Tom runs 12 miles per hour. Which one will reach the telephone pole first? Tom, you say. But what if Tom decides to run the other way first? To be sure about which boy will reach the pole first, you must know which way they are running. You must know their *direction*.

Speed and Velocity

You know that the speed of an object is the distance it travels in a certain amount of time. If you walk at a speed of 4 miles per hour, in one hour you have gone 4 miles. Your younger brother or sister may walk at a speed of 2 miles per hour. Your father may drive his car on the road at 60 miles per hour. The earth moves in its orbit at the speed of about 18 miles per second.

But just as important as speed is the direction in which an object travels. How fast an object travels *in a certain direction* is called the **velocity** (vuh-LAHSS-uh-tee) of the object. If you walk 5 miles per hour north, in one hour you will be 5 miles north of the place where you started. Your younger brother or sister may walk 2 miles per hour east. Your father may drive 60 miles per hour west.





A racing-car driver whizzes around a track at a speed of 100 miles per hour. His speed stays the same at all times. But his velocity keeps changing, because as he goes around the track, he keeps changing his direction. At the top of the diagram, you see an arrow representing the driver's velocity at one instant. This arrow represents 100 miles per hour *eastward*. At the bottom of the diagram is an arrow which represents a different velocity. He is traveling at the same speed, but in the opposite direction. The arrow at the bottom represents a velocity of 100 miles per hour *westward*.

The velocity of the racing car driver, of the earth, of your father's car, or of anything is a quantity called a **vector** (VEK-ter). A vector has both size and direction. Velocity vectors are one type of vector. They tell *speed* and *direction*.

Vectors are represented by arrows. After you have determined the direction of movement, you can draw a velocity vector by drawing a line and putting an arrow tip on one end of it to show its direction. After you measure the speed of movement, you make a scale in much the same way a map-maker does. You may decide that one-quarter inch on the line represents 5 miles per hour. It could represent 1,000 miles per hour or any other speed you choose. For the vectors drawn in the racing car diagram, one-quarter inch represents 25 miles per hour. The point of the arrow indicates the direction of the car.

pupils appreciate the difference between a speed and a velocity as described in the text.

- *Can you give any examples of objects that have a speed but no velocity?*

In fact, there are none in the every-day world of experience. All motion is a vector quantity.

- *Can you think of any examples of objects that have a constant speed but have a constantly changing velocity?*

There are dozens of examples of these; anything that is moving in a circular direction can have a constant speed but a changing velocity. Examples include horses or cars on a racetrack, satellites orbiting the earth, the earth orbiting the sun, etc. Be sure that you make generous use of the chalkboard when explaining the differences between speed and velocity of objects — it will help the pupils' comprehension greatly.

ADDITIONAL ACTIVITIES:

Ask the pupils to use the chalkboard to explain how the lengths of the vector arrows indicate relative velocities. Problems involving circular motion can be posed, and the pupils can be asked to indicate how these motions can be described by graphs and arrows.

TEACHING SUGGESTIONS
(pp. 28–29)

LESSON: How are vectors added to or subtracted from each other?

Background: The section *Combining Vectors* is concerned with the simple addition and subtraction of vectors using diagrams. Adding two vectors that are moving in the same direction is identical to adding two groups of the same kind of object. Subtracting two vectors moving in exactly opposite directions (a difference of 180°) is identical to subtracting two such groups. Vectors, however, indicate the motion of objects in the real world, so far as we are concerned at this point, and this is the reason they are used.

Learning to add and subtract velocities in the simple fashion described in this section is a necessary introduction to the addition and subtraction of velocities that are not moving in the same or opposite directions; such situations are covered in the next section.

Learnings to Be Developed: Velocities can be added to or subtracted from each other by using diagrams.

Developing the Lesson: The best way of developing the idea of adding and subtracting vectors is to discuss the text while drawing the

Draw vectors to show the speed and direction of each man below. Let one inch equal 4 miles per hour.

1. A man walking at 1 mile per hour eastward.
2. A man walking at 4 miles per hour eastward.
3. A man running at 9 miles per hour eastward.
4. A man running at 9 miles per hour westward.

Now draw these vectors. Make up your own scale.

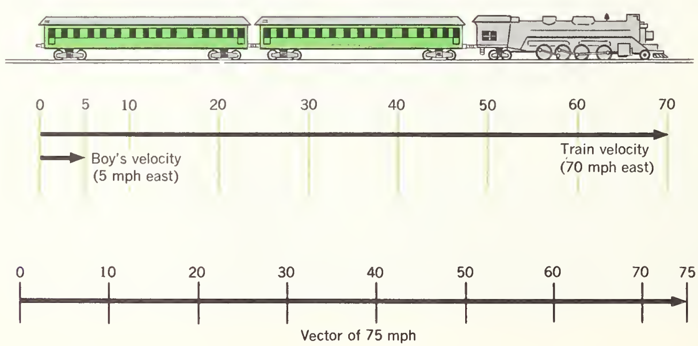
1. A snail moving 1 foot per minute northward.
2. A pencil rolling 5 feet per minute southward.
3. Smoke drifting 20 feet per minute eastward.

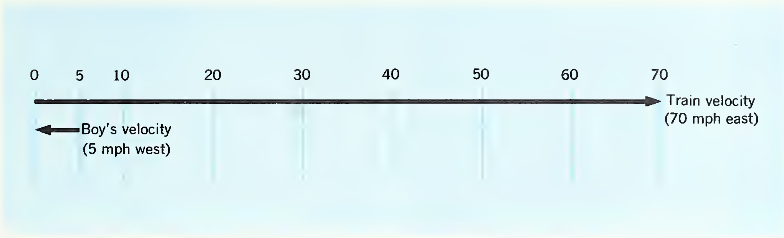
Combining Vectors

In the picture below you see a train traveling eastward at 70 miles per hour. Beneath the train you see a vector representing its velocity. A boy on the train gets up and walks quickly toward the front at 5 miles per hour. You see the vector representing his velocity. Is he going faster than the train?

It does not seem so to the other passengers. To them, the boy seems to be moving at 5 miles per hour. But what about his velocity as seen by an observer standing still on the ground? To the observer, the boy seems to be moving even faster than the train. Actually, his velocity in relation to the ground is 75 miles per hour eastward.

Notice how the vectors are drawn. Both point the same way. What does this tell you about the direction of the train and the boy?



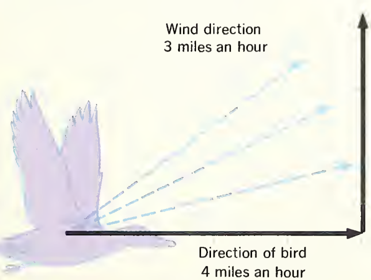


Now the boy hurries back to his seat at the same speed, 5 miles per hour. His velocity is 5 miles per hour westward. What is his velocity seen by the observer standing still on the ground?

Again you can combine the vectors. But notice that they are in opposite directions, so the resulting vector is 65 miles per hour eastward. You have to subtract the boy's speed from the train's speed to get his velocity as seen by someone watching the train pass.

Another Kind of Vector Problem

Here is another type of vector problem. A bird flies 4 miles per hour *eastward*. The wind blows 3 miles per hour *northward*. What is the bird's velocity as seen by an observer standing still on the ground?



Notice how this problem differs from that of the boy on the train. The boy was walking in one direction and the train was moving in the opposite direction. In this problem the wind is blowing at right angles, like this: └ or ┐ or ┌ or ┘, to the flight of the bird. The bird flies straight eastward, but it flies in a stream of air that is moving in a northward direction. The heavy line shows the bird's aim, and the dotted lines show how the wind changes the bird's course.

It is easy to see that the wind is changing the bird's direction. Does it also change the bird's speed? Will a bird flying at 4 miles per hour in relation to the ground go faster, slower, or at the same speed when a 3-mile-per-hour wind blows at it from a right angle?

appropriate vector quantities on the chalkboard. The lesson is essentially visual and can best be understood with the help of simple diagrams that accompany the discussion.

Follow-Up: Set simple problems for the pupils to solve at the chalkboard. As they grasp the ideas, you can ask questions that involve more complicated back-and-forth motions.

- *How would you diagram the behavior of a bouncing ball that gradually comes to a stop after a number of bounces?*
- *Describe the motions of two boys who start from opposite ends of a moving train and walk toward each other.*
- *If they start walking at the same moment and the train is moving at 50 mph, how fast will each boy walk relative to the outside world?*

(pp. 29–31)

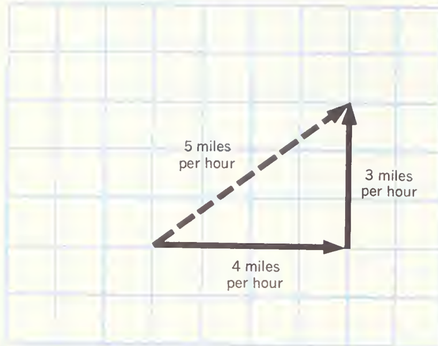
LESSON: How can you combine vectors that show different directions?

Background: This section continues the development of the concept of vectors, but in these problems the forces determining the direction of the object are acting at

right angles to each other. Mathematically, the problems are nothing more than examples of Pythagorus' Theorem, but they are so designed that the pupils can scale off the distances accurately.

Learnings to Be Developed: The forces acting on an object can be added together to find the true path of the object.

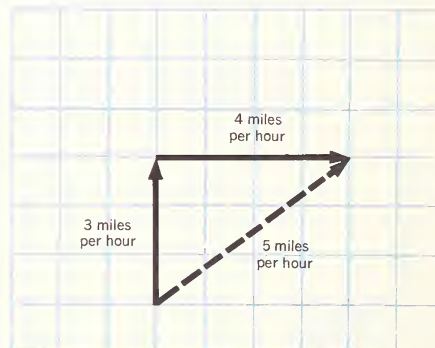
Developing the Lesson: You can begin by reviewing the content of the previous lesson and point out that many times "outside" forces act on moving objects. In the examples previously discussed, the train and the boy moved of themselves; the boy, at least, could change his direction as he pleased. You can then introduce the examples of a boat moving in a stream of water or an airplane flying in a moving stream of air. In these examples there are two forces that can influence the direction in which the objects are moving—the motion of the object itself and the outside force pushing the object in the same or another direction. In discussing the examples given in the text, draw the graph lines and the vectors step by step, discussing the vector forces in detail to be sure that the pupils understand how the forces act upon the object and how the resultant vector is calculated. You must be accurate in drawing the graph lines and in marking the lengths of the vectors



You can use vectors to solve this kind of problem, too. A vector is drawn representing the velocity of the bird. In the diagram, one-quarter inch stands for 1 mile per hour, so we need four times that length, or one inch, to stand for 4 miles per hour. The arrow tip shows that the direction is eastward. From the arrow tip of this vector another vector is drawn. It stands for the velocity of the wind, which is 3 miles per hour northward. Notice that a line three quarters of an inch long is needed to show this. The tail of the first vector and the tip of the other are connected by a dotted line. An arrow is drawn on it because it, too, is a vector. This new vector represents the velocity of the bird as seen from the ground. Notice that it is in a northeasterly direction. Measure the vector. Can you tell how fast the bird is going?

It does not matter which vector you start with. Just put the tail of the second vector at the tip of the first vector. In the drawing below, the wind vector is drawn first. The answer is the same.

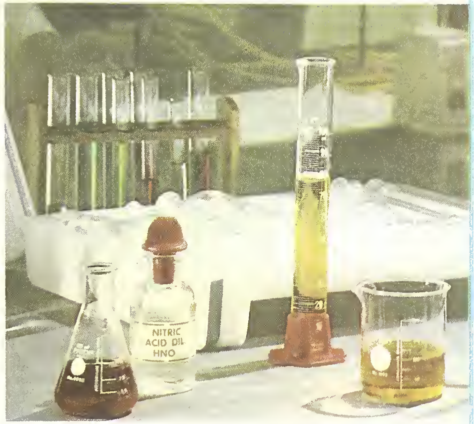
Vectors are used to represent any quantity that has direction. The force exerted by you on your chair is a vector quantity. The force is the pull of gravity downward on your mass. Magnetic force, electrical force, and all other forces are vector quantities. By using vector diagrams like those in this unit, scientists can find the result when several forces act on an object, just as you found the velocity of a bird flying on a windy day.



Pythagoras' theorem states that the square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides: or $c^2 = a^2 + b^2$

The Scientist and Measurement

In this unit you have learned the importance of making exact measurements and using standard units. You have seen how we use measurements to help us solve many different kinds of problems. You have learned how we use formulas, graphs, and vectors to help us see relationships quickly and clearly. Measurements also help the scientist to understand the world around him better. They help him to explain things that earlier scientists could not understand. Measurements also show that things are not always what they appear to be. Tell about times in your life measurements have shown things to be different from the way they appear to be.



In the picture, you see some of the tools of the chemist. Notice that the beakers, flasks, and cylinders all have units of measurement printed on them. Why are measuring instruments vital to the work of the chemist?

Using What You Have Learned

1. A bird is flying 15 miles an hour northward. The wind is blowing 5 miles an hour northward. What is the velocity (speed and direction) of the bird as seen by an observer standing still on the ground?

2. Another bird flies 15 miles an hour southward, while the wind is blowing 5 miles an hour northward. What is the bird's velocity as seen by an observer on the ground?

3. Another bird flies 15 miles an hour northward. The wind blows 15 miles an hour southward. What is the bird's velocity as seen by an observer on the ground?

on the lines, or the resultant vector will not come out to scale, and an incorrect answer will be indicated.

TEACHING SUGGESTIONS
(p. 31)

Background: The answers to *Using What You Have Learned* are:

1. The observer sees the bird flying north at 20 miles per hour.

2. The observer sees the bird flying south at 10 miles per hour.

3. The bird seems stationary to a ground observer.

Follow-Up: The pupils can solve other problems, using graph paper. For example, a man rows across a river at a rate of 12 miles per hour. The river flows at right angles to the boat's direction at the rate of 5 miles per hour. How fast is the boat moving in relation to the river bottom, and in what direction? (13 miles per hour, at an angle of 67°23′ from the flow of the river.)

In fact, it is not necessary that the vector forces be at right angles. For example, an airplane moves in various directions over the countryside. If the distances are scaled off accurately, combining the vectors gives a vector that is the straight line between the point at which the airplane started and the point at which it landed.

(pp. 32–33)

Background: These two pages constitute a review of the concepts and terminology introduced in the unit.

What You Have Learned: This is a summary of the entire unit, with new words in boldface type.

Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390-393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

Complete the Sentence:

1. volume
2. sea level
3. mass
4. gravity
5. velocity

Comparing Metric with English Units:

1. kilometer
2. centimeter
3. kilogram
4. meter

Note: These are the nearest standard units, not equivalent measurements.

WHAT YOU KNOW ABOUT

The Scientist's Way

What You Have Learned

Measurements help the scientist to understand the world around him. Measuring things exactly is often part of a scientist's work.

Standard units of measurement are those that everyone agrees to use. The foot and the pound are standard units in the **English system** of measurement. The meter and the gram are standard units in the **metric system.** Most units of measurement are not natural units; only the day and the year come close to being natural units.

Mass is the amount of **matter** in an object. **Volume** is the amount of space an object occupies. The mass of an object never changes, but the volume and weight of an object change according to its temperature and its distance from the center of the earth.

A **formula** is a statement of a relationship among units of measurement. A graph is a picture of such a relationship.

A **vector** quantity has both size and direction. **Velocity** is a vector quantity, for it is a measurement of both the speed and the direction of a moving object.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

accelerate	mass	standard units	velocity
formula	sea level	vector	volume

Complete the Sentence

Write the numbers 1 to 5 in your notebook. Next to each number write the answer that best completes the sentence.

1. The amount of space a substance occupies is its ___?___.
2. The level of the surface of the sea is the __?__ __?__.
3. The amount of matter in an object is its ___?___.
4. The pull toward the center of the earth is called __?__.
5. How fast an object travels in a certain direction is its ___?___.

Comparing Metric with English Units

Which unit in the metric system is closest to each of the following units:

1. mile?
2. inch?
3. pound?
4. yard?

Can You Tell?

1. What are the differences between natural units and standard units? Give examples of natural units and standard units.
2. How does the English system differ from the metric system?
3. What is the unit of mass in the metric system? What is it in the English system?
4. How does the Fahrenheit scale for measuring temperature differ from the Centigrade (Celsius) scale?
5. How would you go about finding the weight of a heavy object such as a boulder without using scales to weigh it?
6. Why do scientists prefer the metric system to the English system of measurement?

Can You Tell?

1. Natural units are those based on natural phenomena; standard units are units that everyone has agreed to use.

2. The English system is based on the pound, the yard, and the second; the metric system is based on the meter, the kilogram, and the second.

3. The kilogram; the pound.

4. The points at which water freezes and boils have been given different designations and the interval between these points has been subdivided into a different number of units. Both thermometer systems are based on the same points, however.

5. Weigh a small piece of the boulder on a scale and then find its volume by placing it in a calibrated container. Then find the volume of the entire boulder. Its weight can be found by proportion.

6. For its consistency throughout all phases of mensuration–volume, distance, and mass.

TEACHING SUGGESTIONS
(pp. 34–35)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

What Are the Words?

1. English system
2. matter
3. gravity
4. sonar
5. accelerate
6. vector
7. volume
8. metric system
9. velocity
10. mass

YOU CAN LEARN MORE ABOUT

The Scientist's Way

What Are the Words?

Write the words in your notebook.

1. The system in which the inch, the foot, and the mile are standard units.
2. The substance of which all objects are made.
3. The attraction between two objects.
4. The instrument on a submarine that uses sound to measure distance.
5. To increase in speed.
6. A quantity, represented by an arrow, that has both size and direction.
7. The amount of space something occupies.
8. The system in which the centimeter and the meter are standard units.
9. How fast an object travels in a certain direction.
10. The amount of matter in an object.

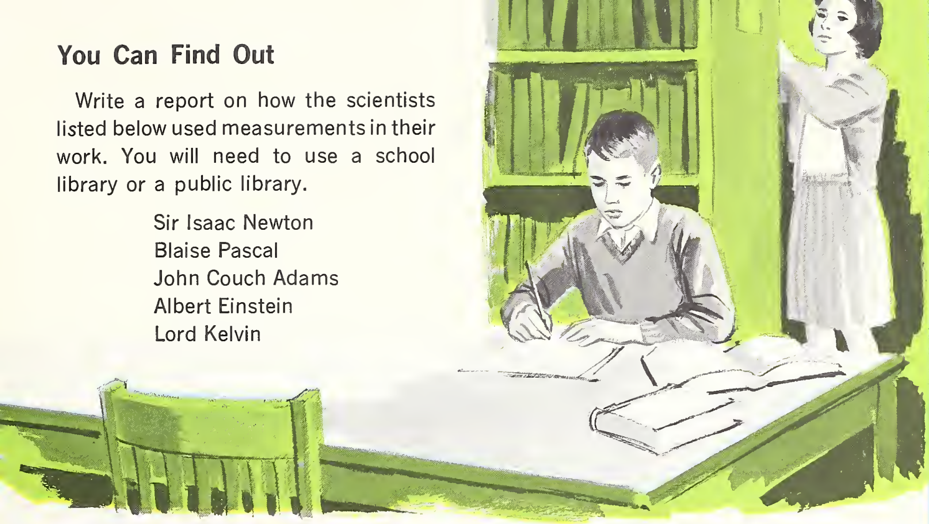
You Can Make a Time Line

A time line is a series of pictures that shows how something developed. Make a time line to show how our system of measurement has developed from earliest times to today. For ideas, read the books listed under **You Can Read.**

You Can Find Out

Write a report on how the scientists listed below used measurements in their work. You will need to use a school library or a public library.

Sir Isaac Newton
Blaise Pascal
John Couch Adams
Albert Einstein
Lord Kelvin



You Can Read

1. *Things That Measure,* by Philip B. Carona. A history of measuring instruments together with simple home experiments.
2. *Mathematics: The Language of Science,* by George O. Smith. Traces the development of mathematics and discusses Galileo, Newton, and others.
3. *Take a Number,* by Jeanne Bendick and Marcia O. Levin. Numbers—from finger counting to computers—are explained.
4. *New Ways in Math,* by Arthur Jonas. The story of mathematics from the days of bartering to the space age.

Additional Readings:

The Giant Golden Book of Mathematics: Exploring the World of Numbers and Space, by Irving Adler (Golden, 1960). Colorful illustrations, many diagrams.

Realm of Measure, by Isaac Asimov (Houghton, 1960). Theories, history, and tools of measurement.

Albert Einstein, by Arthur Beckhard (Putnam, 1959). His life and theories.

The First Book of Time, by Jeanne Bendick (Watts, 1963). Time as a dimension, related to space and motion; the calendar; natural and mechanical clocks; relativity.

How Much and How Many: The Story of Weights and Measures, by Jeanne Bendick (Whittlesey, 1960). Different types of measurement and their history; encourages appreciation of scientific exactness and organization.

School Science and Mathematics, Central Association of Science and Mathematics Teachers. Monthly journal, October-June.

The Romance of Weights and Measures, by Keith Gordon Irwin (Viking, 1960). Development of English system.

The Quest of Isaac Newton, by Barbara and Myrick Land (Garden City, 1960). Good organization and attractive illustrations.

KEY CONCEPTS

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 3. To find order in the natural environment, the scientist seeks basic units than can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.

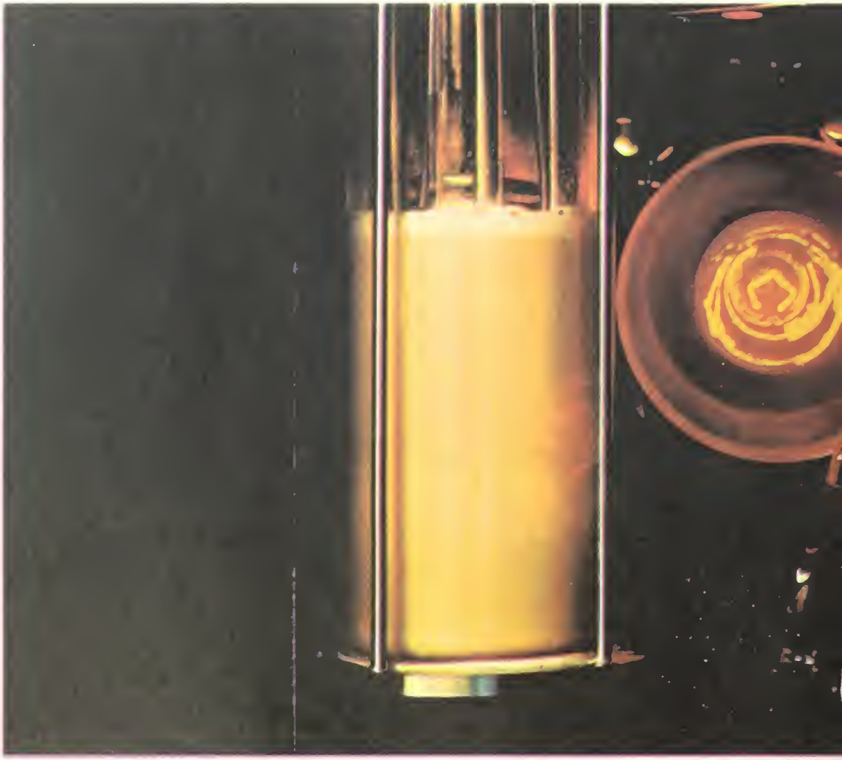
Key Concept 4. All objects in the universe and all particles of matter are constantly in motion; man has discovered and stated the laws governing their motion.

Key Concept 5. The motion of particles helps to explain such phenomena as heat, light, electricity, magnetism, and chemical change.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. The evidence of the world about us leads scientists to conclude that molecules exist, al-



2

Other concepts appear under "Learnings to Be Developed" in each lesson found in the Teaching Suggestions.

Heat and Molecules

Molecules and Matter

How Do Objects Become Heated?

though molecules cannot be directly observed.
2. Molecules are extremely small and in constant motion.
3. The arrangement of molecules determines whether a substance is a solid, a liquid, or a gas.
4. Changes in state can be explained as the result of increased molecular energy (motion).
5. Objects may become heated by radiation and conduction.
6. Volume increases when heat is added.
7. Heat may be transferred either by conduction or by radiation.
8. Temperature is a measure of the average speed of all the molecules in a substance compared with water as a standard.
9. There is a difference between heat and temperature.

PROCESSES:

- Observing—Pages 40, 42, 43, 44, 48, 50, 52, 53, 54, 57.
- Experimenting—40, 42, 43, 48, 52, 53, 54, 57.
- Comparing—40, 42, 43, 44, 48, 50, 52, 53, 54, 57.
- Inferring—40, 42, 43, 44, 48, 50, 52, 53, 54, 57.
- Measuring—53, 54.
- Selecting—38, 39, 51, 57.
- Demonstrating—44.
- Explaining—40, 48, 50, 51, 52, 53, 54, 57.
- Hypothesizing—42.

TEACHING SUGGESTIONS
(pp. 38–39)

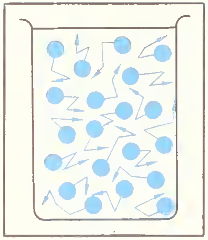
● **LESSON:** Why do scientists believe that molecules exist?

Learnings to Be Developed: The evidence of the world about us leads scientists to conclude that molecules exist, although molecules cannot be directly observed.

Developing the Lesson: The class discussion can begin by assuming the conclusion — molecules exist. Even for sixth graders, the existence of molecules can be taken for granted. The effort of the class should therefore be directed to *why* scientists believe in molecules. The five points can be discussed from this point of view.

As for point 1, it should not be difficult to find examples of each of the three states of matter. In fact, challenge the class to find examples that *don't* fit into one of the three categories. Point out that no matter how small a sample there is of a substance, it still remains that substance. It is easy to conclude that even if a sample is too small to be seen, it still remains that substance.

As for point 2, that substances change from one state to another if they are cooled or heated is a matter of common observation. Point out that water has different



Look at the objects shown on page 36. They all look different. Yet they are also alike. Scientists use the word *matter* when they talk about what all objects are made of. Rocks, water, air, and you are matter. Matter is made up of molecules. Rocks, water, air, and you are made of molecules.

Molecules and Matter

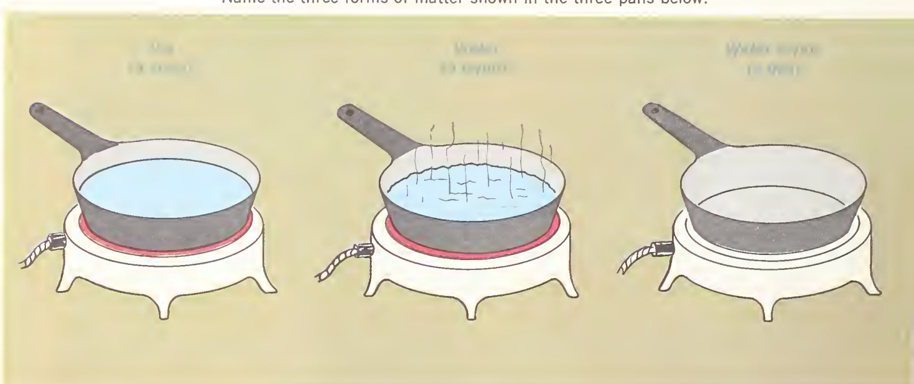
There are five important ideas that will help you to understand the new ideas in this unit.

1. Matter may be in one of three states: solid, liquid, or gas. Can you give some examples?

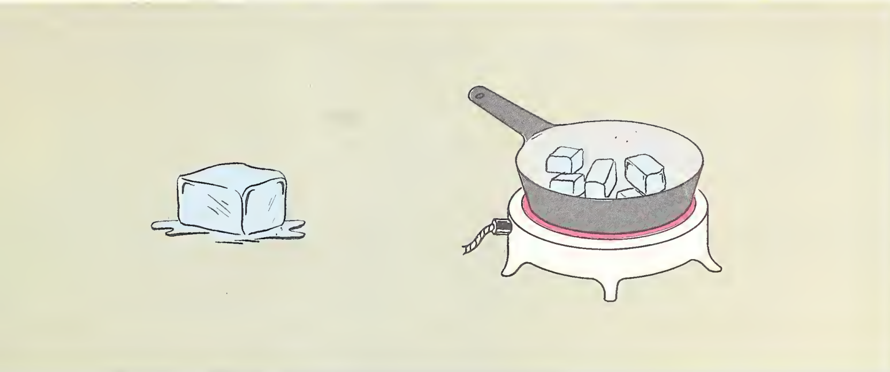
2. A substance such as water can be changed from a solid to a liquid and then to a gas by heating it.

3. Some substances, such as sugar, dissolve in water. When sugar is dissolved in water you can no longer see the sugar. You know it is there because the water tastes sweet. Matter may change its form, but it cannot disappear completely. Sugar added to water increases the amount of matter in the glass, whether or not you can see this happening.

Name the three forms of matter shown in the three pans below.



By studying the behavior of matter in its three states, students can be led to the conclusion that a molecular theory can best explain this behavior. In a sense, this is the point of this entire unit, so this lesson serves as an introduction of what is to come.



How is the ice changed from a solid to a liquid and then to a gas?

You also know that when heat is added to water, substances such as bouillon cubes will mix with the hot water faster than they will with cold water.

4. An atom is the smallest particle of an element. For example, the smallest particle of copper is an atom of copper.

5. A molecule is the smallest particle of a substance that has all the characteristics of the substance. A molecule of water is the smallest particle of water that can exist and still be water. A molecule of water contains two hydrogen atoms and one oxygen atom. If a water molecule is broken up into smaller particles, the particles are atoms of hydrogen and oxygen.

How did scientists find out about molecules if molecules cannot be seen? They found out in very much the same way that you might. For example, you enter a room. You find a toy block, a small shoe, cookie crumbs, or crayon markings on a piece of paper. You say, "My little brother has been here." You did not see or hear your brother, but from the evidence around you, you get the idea that he has been there. The little-brother idea seems to be a good one to explain why things are topsy-turvy.

This is something like the way that scientists formed their ideas about molecules. They developed the idea in order to explain many things that they observed with their senses.

characteristics in each of its three states. The chief difference between the states is the relative rigidity of the water. This must be true of even the smallest sample of ice, steam, or water, which means that molecules behave with respect to each other in the same way. Below a certain temperature, the molecules are locked into position; when heat is applied, the molecules are free to move around one another.

As for point 3, the discussion brings up the point that solids will dissolve in liquids. Even though they disappear entirely, evidence of their presence remains, such as the sweet taste of sugar dissolved in water, the salty taste of salt dissolved in water, and the dyeing of water with colored chemicals. No matter how small the sample is of sweetened water, for example, it will still taste sweet; and no matter how small the sample of dyed water, it still has the color of the dye. This leads to the conclusion that the molecules of these substances have the same characteristics that the gross samples do. Furthermore, the fact that solids disappear when dissolved in water shows how small the molecules are.

Points 4 and 5 are conclusions reached from a discussion of the first three points.

TEACHING SUGGESTIONS
(pp. 40–41)

● **LESSON:** How are odors carried from one part of a room to another?

Learnings to Be Developed: Diffusion of odors can be explained by assuming the existence of molecules.

Developing the Lesson: Point out the word "observation" in the activity. Have someone look up the word in the dictionary. Have someone else look up "experiment." Compare the two definitions.

Go on to reading the procedural steps 1 and 2 of the observation and then ask:

• *Is this an experiment?*

Point out that while observations are not experiments in the true sense, all experiments depend on observations and interpretation of these observations. Observation alone, without interpretation by the mind, is not very fruitful. The scientist investigates as much as possible the meaning of what is observed. The pupil does this by answering the questions.

The onion is effective, but other pungent or odoriferous substances could be substituted, such as inexpensive perfume or cologne in an open saucer.

Evidence of Molecules from the Sense of Smell

Has your mother ever left a bottle of perfume open? Perhaps your father has left a can of paint open. Or maybe your mother makes roast beef for supper. You can smell all these things from a good distance away. The smells of perfume, roast beef, and fresh paint are all one kind of evidence that supports the idea of invisible molecules. Can you tell how?

OBSERVATION

Does the Sense of Smell Give Evidence of Molecules?

What You Will Need

onion knife

How You Can Find Out

1. As the entire class faces the front of the room, have someone go to the rear of the room and cut the onion in half.
2. Have members of the class raise their hands when they smell the onion.

Questions to Think About

1. Did the people nearest the onion or farthest from it smell it first?
2. Did they see anything move from the onion to their noses? How, then, could they smell it?
3. How could you explain what happened?
4. Invisible molecules must have moved from the object to their noses. How?
5. You might want to try some other objects to see if your sense of smell gives evidence of molecules. Try using perfume, glue, paint, household cleanser, and baby powder. Try timing how long it takes the class to react to each. How do you account for the differences in reaction time?

It is important that you keep the distinction between diffusion and currents of air in mind. In perfectly still air, odors would travel very slowly and would take days to cross a small room by the process of diffusion. It is the air currents in a room that carry the odors from one place to another.

Molecules from the onion that produce the odor escape into the air. But why did they escape? Molecules are in constant motion. They move in all directions and constantly bounce into each other. Therefore, when the onion was cut, some of the bouncing molecules escaped into the air. Since the molecules of the gases that make up the air are also constantly in motion, they helped to bounce the other molecules along from the onion to the members of the class.

You can observe what happens when the bouncing molecules of water hit small objects. Mix a tablespoonful of homogenized milk in one-half cup of water. Put a drop of the mixture on a microscope slide. Place a cover slip over the drop and examine under a microscope. You will see small bits of milk fat distributed throughout the water. As you observe these bits of fat, you will notice that they appear to be shaking. They shake, or vibrate, because they are being bombarded by invisible water molecules.

The movement of molecules from a source such as the onion throughout the air in a room is caused by currents of air carrying the molecules.

Molecules of one kind of matter also move from an area where there are many such molecules to an area where there are fewer such molecules. There are more molecules in the onion particles closer to the onion. These molecules move slowly out into an area where there are not so many. This process is called **diffusion.** Now can you explain why you can smell paint and roast beef from a distance?

• *Is what you have observed evidence that molecules exist?*

It is evidence that something not perceived by the eyes was perceived by the nose. It is evidence that something invisible gradually spread about the room. That something may be called "molecules."

Follow-Up:

Obtain a 1″ square from the gray area of a newspaper picture. Hold it up against a light background and ask the class if they can see it. Then pass it around the class with a hand lens (or use an overhead projector), and the children will notice that it is composed of tiny dots with spaces between. On a large piece of construction paper or the back of a wall map scatter a few dozen pencil dots far apart from each other.

Widely scattered dots are harder to see than dots of the same size that have little space between.

Caution: Emphasize that the visible particles of milk are not molecules but clusters of thousands of molecules in fat globules. The water molecules and milk molecules cannot be seen even with a high-powered optical microscope.

TEACHING SUGGESTIONS
(p. 42)

Background: This observation should be conducted by demonstration and questioning, since the materials might not be available for all the pupils. But follow up the demonstration by assigning pupils individual observations on other substances to be made at home. Suggest that they follow the general procedure outlined on this page and vary the solvent (milk, water, vinegar, liquid detergent, salad oil, etc.) and the solute (ink, food coloring, starch, instant coffee or tea, etc.). Assign groups specific combinations. Have them record their findings for discussion the following day. Caution children against using medicines or chemicals of unknown characteristics without supervision.

Add a few questions of your own to bring out the understanding of molecular *diffusion*.

Answers should indicate that water molecules and any mineral matter and dissolved gases are also in ceaseless motion.

Randomness or chaos should be observed. However, some substances, being more dense than others, may exhibit diffusion *and* a tendency to gravitate to the bottom. Explain that in any system there are several forces at work simultaneously.

Evidence of Molecules from the Sense of Sight

Do molecules also spread out in liquids? If so, can you see it happen?

After you do the activity to find out if your sense of sight gives evidence of molecules, try to think of other ways to show that molecules move.

OBSERVATION

Does the Sense of Sight Give Evidence of Molecules?

What You Will Need

ink
water
glass bottle with one-holed rubber stopper
medicine dropper

How You Can Find Out

1. Put water in the glass bottle.
2. Place the one-holed rubber stopper in the bottle.
3. Put some ink in a medicine dropper.
4. Place the dropper in the hole of the stopper. Squeeze one drop of ink into the water.

Questions to Think About

1. What do you see? Why?
2. Did you hypothesize that ink is heavier than water and that is why it is pulled down?
3. Turn the bottle sideways. Does the action continue?

You can see that it is not only gravity that forces the molecules to the bottom. Something else is happening. No matter which way you turn the bottle, you will see the water in the entire bottle slowly turn blue.

Particles of ink are being carried through the water by the movement of water molecules. The particles of ink diffuse through the water. They move from an area where there are many such particles to an area where there are fewer.

Try the same activity with a gallon jar of water and one drop of ink. Can you see the ink? You know the ink particles are there. You see their outward movement, but the particles become so far apart that they do not change the color of the water.

More Evidence of Moving Molecules

The activities you have done show evidence that molecules not only exist but also move. There are other ways of gathering evidence for molecules.

Have you ever seen substances disappear? Put one teaspoonful of salt in a glass of water. Stir. Can you still see the salt? Now taste the solution. How does it taste? Boil the solution until all the water evaporates. What do you see in the pan when all the water is gone?

When you stirred the salt in the water, the crystals of salt separated into particles that you could not see. In fact, even with the most powerful microscope, scientists cannot see particles of salt dissolved in water. When you tasted the solution, you proved that the salt molecules were still there. How? When you boiled the solution until all the water evaporated, you noticed that the particles of salt formed crystals again. What caused the crystals to break up when they were put into water?

Using the many kinds of evidence that you have just read about, scientists have come to believe that molecules exist and move about.

Note: the hemoglobin molecule (a large one) is about 1/4,000,000 (4 x 10[illegible]) of an inch; a hydrogen molecule (a small one) is about 1/80,000,000 (8 x 10^{-7}) of an inch. A drop of liquid contains approximately 10^{20} molecules—1 followed by 20 zeros.

TEACHING SUGGESTIONS
(p. 43)

LESSON: How can we find out the approximate number of molecules in a drop of ink?

Learnings to Be Developed:
Molecules are too small to be observed.

Developing the Lesson: Ask for suggestions on how the question above could be answered by an investigation in the classroom. If none proves feasible, try this:

Fill a glass with water. Thoroughly mix in *one* drop of ink. Estimate the ratio of the volume of ink to the volume of water (possibly 1 to 1,000). You have now diluted the ink molecules 1,000 times, and you still see their effect. Obviously, there must be more than 1,000 molecules in the original drop.

Add a drop of the bluish mixture to a second glass of water. You should still be able to see the bluish tint.

Calculate the original drop in terms of your new dilution ($1/1{,}000 \times 1/1{,}000 = 1/1{,}000{,}000$, or 10^{-6}). Obviously, even though the original drop of ink is now, in effect, 10^{-6} times smaller, its effect is still visible. The molecules of the original drop still cannot be seen, so they must be at least a million times smaller than the original drop of ink.

TEACHING SUGGESTIONS
(p. 44)

● LESSON: How do molecules behave in solids, liquids, and gases?

Learnings to Be Developed: The arrangement of molecules determines whether a substance is a solid, a liquid or a gas.

Developing the Lesson: Read and discuss page 44. Discuss the diagram at the bottom of the page as you proceed. The models, from left to right, are *analogs* of solid, liquid, and gas states.

Reinforce the ideas of the three states or phases of matter by this set of analogs:

Have ready, before class begins, a light source producing a strong beam of light, such as a filmstrip projector; a piece of chalk; and a glass half filled with chalk dust.

Exhibit the chalk stick.

• *What state of matter is the chalk in?*

Exhibit the glass of chalk dust. Agitate it a bit back and forth by hand motion. Explain that although the dust is not really liquid, it comes close to behaving as a liquid does. For example, if you place a pencil in it, the space closes when you remove the pencil.

How Do Molecules Behave in Solids, Liquids, and Gases?

All solids have one thing in common that is different from liquids and gases. They tend to keep their shape.

A model will help you understand how molecules behave in solids and why solids keep their shape. Imagine some marbles packed in a box so that the entire bottom is covered. If you tilt or wobble the box a little, the marbles move, but they do not move past one another. Their arrangement in the box is fixed, or locked.

A liquid such as water does not have a fixed shape, as solids do. A liquid takes the shape of the container in which it is put. The arrangement of the molecules in a liquid is not fixed or locked. It is *fluid*. The molecules are always slipping and sliding past each other.

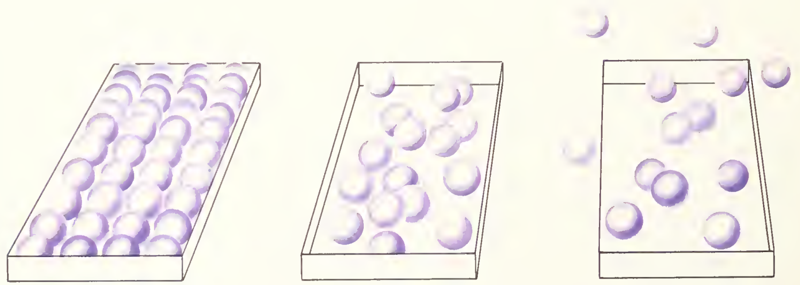
The molecules in a gas have no fixed position. They are constantly in motion with no particular pattern. They bounce off each other in all directions.

The molecules in a gas move more rapidly than do the molecules in a solid. They also move farther apart from each other.

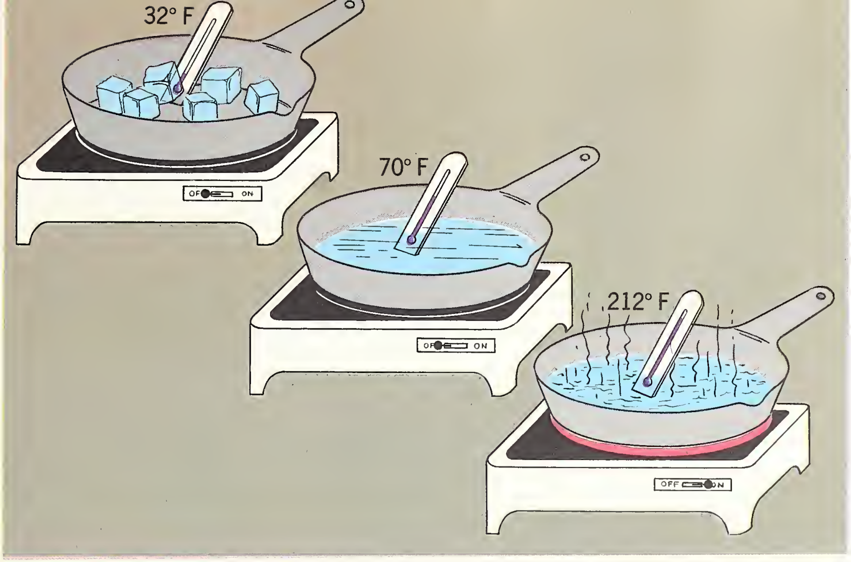
When the position of molecules is fixed, the particles move about less. More of them can fit into a certain amount of space. For example, a box would hold fewer particles of matter existing as a gas than of the same matter existing as a solid.

The arrangement of molecules determines whether matter is a solid, liquid, or gas.

Can you tell which model shows a liquid, which a solid, and which a gas?



Get the room as dark as possible. Now place some chalk dust on two board erasers, and clap them together moderately hard in front of the lighted projector. Point out that the behavior of the dust particles is similar to the behavior of gas molecules.



How are the molecules of water behaving in each pan?

Why Do Molecules Behave Differently in Various States?

Look at the picture above.

How can the idea of moving molecules be used to explain what happened? What did heat do to the water?

As heat was added to the water in each situation, what happened to the molecules? The molecules became more active. They moved more rapidly and farther apart from each other. Finally, they moved so rapidly and so far apart that they all left the pan. When heat was added, water changed from a solid to a liquid and then to a gas.

Scientists now believe that the heat of an object is produced by the motion of its molecules. The faster molecules in an object move, the hotter it is. An object loses heat when its molecules move more slowly. Since molecules in all objects have motion, *all* objects have some heat—even a cube of ice.

Scientists also believe that heating things brings disorder. The molecules move about more and more rapidly and bump into each other more frequently. Cooling things, on the other hand, brings order. The molecules become more fixed in their positions.

TEACHING SUGGESTIONS
(p. 45)

LESSON: How can the motion of molecules be slowed down or speeded up?

Learnings to Be Developed:

The addition of heat energy increases the speed of molecules.

The removal of heat energy decreases the speed of molecules.

Developing the Lesson: Refer to the picture of changes of state in water as a result of adding heat. The *conduction* referred to is the direct transfer of heat energy from the hot pan to the water and ice.

Follow the pattern of the text for this page. Then pose the question:

- *Can we slow down or increase motion of liquid molecules?*

To demonstrate possible answers, heat a cup or beaker of molasses until it is steaming. Have a similar amount of molasses cooled in an ice and salt solution (or refrigerator). Pour each liquid into another container and compare time needed to empty each.

- *Which molasses flowed more quickly?*
- *Why do you think the colder one was slower?* (The ice removed some of the heat energy and caused less random movement of the molasses molecules.)

TEACHING SUGGESTIONS
(pp. 46–47)

Background: It might be useful here to review some of the background of Rumford's experiments. Any careful study of the properties of heat depends on accurate measurements, and it was only after the invention of thermometers that careful experiments on heat could be made. The first man to make careful use of thermometers was Joseph Black (1728–1799), who taught both medicine and chemistry at the universities of Glasgow and Edinburgh.

It was Black who first discovered that objects tend to reach a state of thermal equilibrium when they are placed in contact with each other. A cold object warms up and a hot object cools down until they are both at the same temperature. Black also discovered that some substances could absorb a larger quantity of heat than could other substances—that is, they had different specific heats. To account for Black's observations, other experimenters invented the concept of *caloric* (a word first used by Lavoisier).

Caloric was imagined to be a material substance that flowed into or out of a substance and was responsible for its temperature. Different substances could absorb

Benjamin Thompson (Count Rumford)

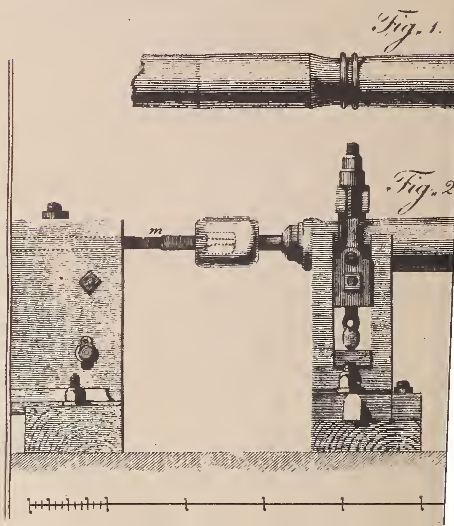
(1753–1814) United States

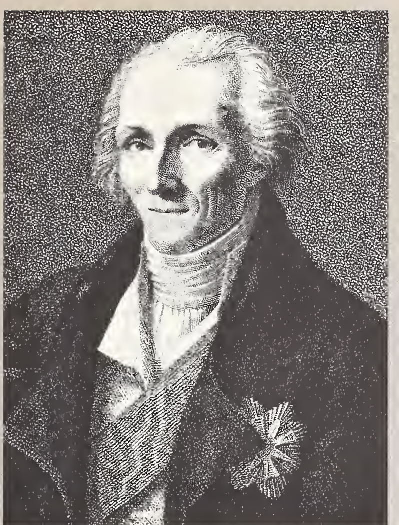
As a young man, Benjamin Thompson tried his hand at many things, including being a medical doctor, a businessman, and a schoolteacher. During the Revolutionary War, he became a spy for the British. During this time, he invented a secret ink so that he could communicate with the blockaded British Army. Arrested for spying, Thompson fled to London. After several years, he went to Bavaria and entered the service of a foreign prince. In Bavaria he gained much power and soon was given the rank of Count. He chose the title of Rumford, the ancient name of Concord, New Hampshire, in honor of the town from which he barely escaped with his life.

Count Rumford (as he is now known) was always very much interested in scientific problems. One problem with which he was concerned was heat. At that time scientists believed that something flowed into objects to make them hot and flowed out of objects to make them cold. They called this something *caloric.* Perhaps you have noticed that when you rub your hands together, they become warm. The scientists of Count Rumford's day said that the hands became warm because caloric flowed into them from the surrounding air.

Does heat really consist of caloric? Count Rumford knew that if caloric were a real substance, as scientists said it was, then it would weigh something. He carefully experimented and found that all objects weighed exactly the same when they were hot as they did when they were

The diagrams are taken from Rumford's original paper in which his gun-boring experiments are described. The diagrams show how the cannon was supported while being bored and the location of the boring tool.



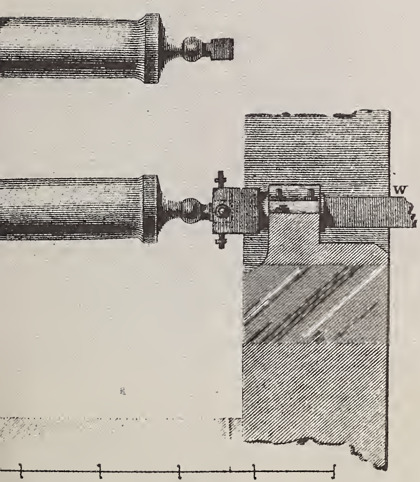


cold. He reasoned then that caloric was not a substance, since it had no weight.

Next Count Rumford noticed that when a brass cannon was being bored in the arsenal, much heat was given off. He conducted more experiments and discovered that *friction*, or rubbing, between the boring tool and the brass of the cannon made the heat. The mechanical energy used to bore the hole was changed into heat energy. Caloric did not make things hot or cold. In fact, caloric did not even exist.

Although Count Rumford discovered that rubbing any two objects together made them hot, he never found out why this was so. Today, scientists know that all objects are made of molecules that are in constant motion, vibrating back and forth. The faster the molecules move, the hotter the object becomes.

Count Rumford was a pathfinder not only because of his scientific discoveries but also because he believed that basic research in a problem provides the groundwork for scientific development.



different amounts of caloric, which accounted for their different specific heats. Caloric could be neither created nor destroyed.

It must not be thought that the caloric theory was simple-minded. In its final form, it accounted very well for all observable properties of heat and enabled experimenters to predict what would happen in experiments with solids, liquids, and gases. The weak point of the theory was that no one succeeded in measuring the weight of caloric.

The importance of Rumford's experiments lay in his showing that it was possible for heat to be created where it did not exist before. This was the chief conclusion of his cannon-boring experiments. He showed that it was impossible for the brass used in the cannon to contain anywhere near the amount of caloric required to account for the heat released during the boring of the cannon.

Although Rumford cast serious doubt on the caloric theory, believers in this theory did not abandon it, since Rumford offered no useful alternative. It was not until others showed that the relationship between heat and work could be explained by a molecular theory of heat, that the caloric theory was finally abandoned.

TEACHING SUGGESTIONS
(p. 48)

Background: The answers to *Using What You Have Learned* are:

1. Heat energy is added to a solid to make it become liquid, which requires greater molecular motion.

2. Heat is added. The change of state from liquid to gas requires additional energy.

3. Heat is taken away.

4. Heat is taken away.

5. Salol, or phenyl salicytate, can be gotten at a drug store. It is an antiseptic. The change of state from solid to liquid occurs when the internal energy of the solid crystal is increased by adding heat. This causes the molecules to move faster, and they break the ties that bind them tighter in a crystalline structure. When cooled again, they return to their original state.

6. Wood's metal is an alloy (mixture of lead, bismuth, tin, and cadmium) that melts at 60° C. (140° F.). Wood's metal is used in fire sprinkler systems; at normal room temperatures it is a solid and thus able to plug the water lines and prevent the flow of water, but with an abnormal rise in room temperature it will quickly melt.

7. When the water is heated, the salol will dissolve. When the water cools, the salol will recrystalize.

Using What You Have Learned

1. When a substance changes from a solid to a liquid, is heat being added or taken away?

2. When a substance changes from a liquid to a gas, is heat being added or taken away?

3. When a substance changes from a liquid to a solid, is heat being added or taken away?

4. When a substance changes from a gas to a liquid, is heat being added or taken away?

5. Put some *salol,* a white crystalline solid, in a test tube. If it has been in your room, what temperature will it be? Heat it briefly. It will turn into a liquid. Then remove it from the heat. In a while you will see salol form into crystals again. Explain what happened in terms of the behavior of molecules.

6. Try to get some *Wood's metal* at a hardware store. Put it in a pan of water and heat it. Take the temperature of the water every two minutes. Observe what happens.

Wood's metal does not need much heat to change from a solid to a liquid. Can you explain why it is often used as a plug in fire sprinkling systems?

7. Put two teaspoonfuls of salol in a jar and leave the jar in your room for several hours. Then do the following:

a. Heat some water to 100° F.

b. Place the jar with the salol in the water.

c. Put a thermometer in the water and continue to heat it.

d. Observe what happens to the salol when the water temperature is about 103° F.

e. Remove the water with the jar of salol from the heat. Does the temperature go up or down?

f. What happens to the salol as the temperature changes?

How Do Objects Become Heated?

If enough heat is added, any solid will change into a liquid and then into a gas. The temperature of matter will rise whenever heat energy is added to its particles. Sometimes it takes a large amount of heat. For example, solid iron melts to liquid form at 1535° C. At what temperature does gold melt?

There are different ways in which energy can be added to the particles in matter to make its temperature rise. You can discover these different ways yourself.

Conduction

Place a silver spoon in a jar of hot water. Keep your hand at the top of the spoon. What happens? How did the heat reach the top of the spoon? How long did it take?

The molecules in hot water are very active. They bounce around rapidly and move farther apart from each other. They have more energy than the molecules in cool water. Some of them bump against the tip of the spoon. The molecules in the tip of the spoon begin

TEACHING SUGGESTIONS
(pp. 49–51)

LESSON: How is heat transferred from one object to another?

Background: This section discusses conduction and radiation. The preceeding pages of this unit were preparation for the introduction of those concepts chiefly in their discussion of molecular motion. The text mentions that molecules exchange or transfer energy by bumping into each other. Your pupils will gain the impression from reading the text that the transfer of energy is analogous to what happens when two billiard balls strike each other, and it would be prudent to let them retain that impression at the present time.

Learnings to Be Developed: Heat may be transferred either by conduction or by radiation.

Developing the Lesson: The information in this section can be developed by asking questions about the pupils' own experiences. Since earliest childhood, everyone has been told not to touch objects that were hot, or they would get burned. Sometimes it was not obvious where the heat came from. The outside of an oven or a hot-water tank, for example, may have been hot. Objects that have been

in the sun have also been hot to the touch.

How do different kinds of objects become hot?

Where does the heat come from?

Two lists can be made up, one of objects heated by conduction (that is, by contact) and the other of objects heated by radiation (that is, at a distance). That objects can become hot by contact seems obvious enough, but that objects can become hot by radiation may be more difficult to understand.

What are these rays that travel through space to heat objects 93,000,000 miles away?

The explanation will have to be by analogy. The children are all familiar with the fact that light (which is a ray) can make objects shine at a distance when its rays strike the object. You can say that heat acts the same way that light does. Since the pupils are all familiar with the fact that light can be transferred by radiation, the analogy will seem reasonable to them.

In the picture on page 50, *radiation* from the sun increases the molecular activity of the rubber ball, the skin and clothing of the boy and girl, the sand, the water, and to a slight degree the air. There is a *conduction* transfer of

to move faster. Some of them bump into molecules in a cooler part of the spoon, adding energy to them. They begin to move faster and farther apart from each other, bumping still others, until the molecules of the whole spoon are moving faster than they were before the spoon was put into the hot water. The spoon becomes hot. Heat has been **conducted** from one end of the spoon to the other. **Conduction** always occurs when objects of two different temperatures touch each other.

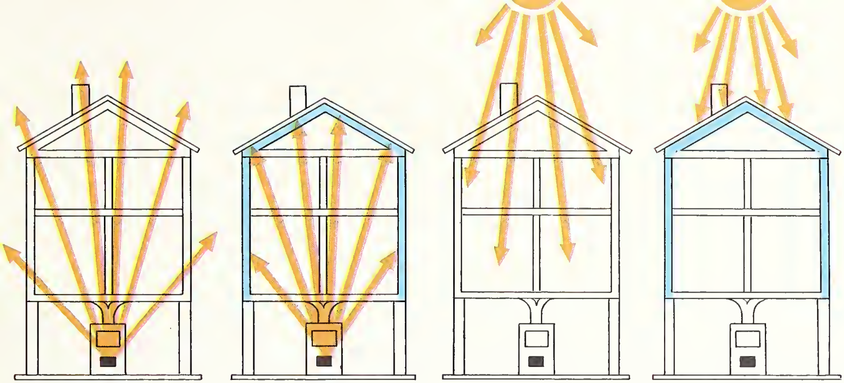
Do all kinds of matter conduct heat equally well? Try different substances in hot water—a stainless steel spoon, a piece of wood, etc. Do they all become hot at the same rate? How can you explain the differences?

Radiation

Objects get warm in another way. The sun warms you even though it is 93 million miles away. The sun is very hot. Rays from the hot sun travel to the earth. When they hit your hand they add heat energy to the molecules in your hand. The molecules in your hand move faster and farther apart from each other, bumping others. Heat is produced, and you feel warmth.

The transfer of energy by rays from the molecules of a warm object to those of a cooler one is called **radiation** (ray-dee-AY-shun). The sun is not the only object that gives off rays. All warm objects give off rays. Can you think of some ways that radiation is used in your home?

Can you explain how the children and objects in the picture below become heated?



WINTER SUMMER

Use what you know about heat and molecules to explain what happens to the houses in the summer and in the winter. How does insulation save money?

Can you explain what is happening in the illustrations above? Use what you know about heat and molecules.

Do you know two reasons that explain your feeling cool in a chilly room?

Expansion and Contraction

You remember that molecules move faster or slower with the addition or removal of heat. However, they do not always speed up or slow down enough to change the state of matter. For example, there may not be enough heat to change a liquid into a gas. What happens to substances when small amounts of heat are added or taken away? Let us first see what happens to solids.

From many experiments with a wide variety of solids, scientists have found that a body becomes heated when its molecules get more energy and move about more. Even in a solid, where their arrangement is fixed so that they cannot pass each other, they are more active.

Can you tell how the principle of radiation is applied to cooking meat in a broiler?

heat energy to parts of the bodies in contact with sand, to water where it rolls over the warmer sand, and to the air.

In the picture on page 51, insulation prevents loss of house heat to the outside in winter and prevents the outside heat radiation from entering in the summer. This is because insulating material is made up largely of trapped air, and air is a very poor conductor of heat. The air therefore prevents the loss of heat from the house during the winter and the entry of heat into the house during the summer.

In a chilly room the human body is at a much higher temperature than that of its surroundings. Therefore heat transfer will be away from your body to the surroundings by either radiation to the air on conduction to any parts of the surrounding room in contact with you. Such loss of body heat causes reactions in some of your thermoreceptors (nerve endings that respond to degrees of heat intensity). These reactions trigger many activities within your body and create a sensation you have learned to call "cold."

TEACHING SUGGESTIONS
(pp. 52–54)

LESSON: How do substances behave when they are heated?

Learnings to Be Developed: The addition of heat causes a substance to expand; the removal of heat causes a substance to contract.

Developing the Lesson: The concepts in this section are introduced by observing what happens during the three experiments. Before doing them, you can review again the general behavior of molecules.

The ring and ball apparatus for the experiment on page 52 may be available in your school. An inexpensive one can be purchased from a scientific supply house.

Caution: When dealing with an open flame, take precautions. A fire extinguisher or pail of water should be handy in the room. Also, to prevent desk damage, have an asbestos pad or hot-dish protector under your apparatus.

The answers to the questions on page 52 are:

1. The ball could not pass through or it passed through with greater difficulty than when ring was not heated.

2. The thermal energy (heat) was transferred to the water. In effect, we say the ring was cooled.

EXPERIMENT

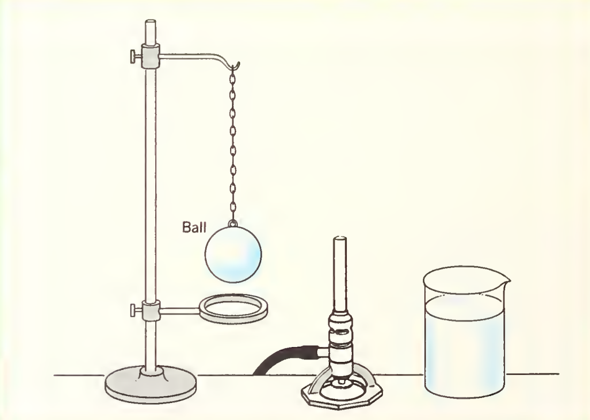
Do Solids Expand or Contract When Heated?

What You Will Need

metal ring large enough for the ball to fit through	ringstand	Bunsen burner
	ball	beaker of cold water

How You Can Find Out

1. Put the ball through the ring with both at room temperature.
2. Your teacher will heat the ring in the Bunsen burner flame for about five minutes.
3. Place the ball in the ring as you did before.
4. Put the ring into the beaker of cold water and try to place the ball through the ring again.



Questions to Think About

1. Can you explain what happened when the heated ring and the ball were fitted together?
2. What effect did the beaker of cold water have on the ring?

Your mother may use what you just learned when she opens a container with a metal cap. If it is difficult to turn the cap, she may hold it under running hot water. When heat is added to the cap, the particles in the cap move about more rapidly and take up more room than before the heat was added. Because the cap expands more than the glass, it is then big enough to be removed easily.

How does a liquid behave when it is heated? Again we use the scientist's way to find out.

EXPERIMENT

Do Liquids Expand or Contract When Heated?

What You Will Need

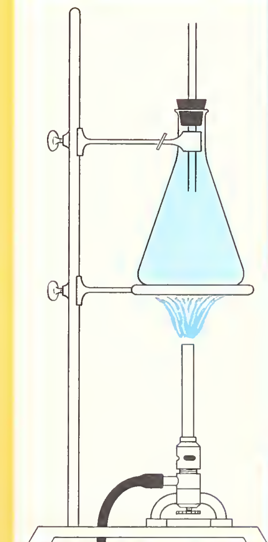
ink	one-holed rubber stopper	flask
8-inch glass tubing		a burner
ringstand		

How You Can Find Out

1. Fill the flask with cold water.
2. Put a few drops of ink into it and stir. This will enable you to see the water better.
3. Put the one-holed rubber stopper with the 8-inch glass tubing through it into the flask. Be sure that the flask is full when the stopper and tubing are inserted.
4. Heat the flask gently.

Questions to Think About

1. What happens when the flask is heated?
2. How can you explain what happens when the flask is heated?
3. After you remove the heat, notice what happens.
4. Do the molecules take up more or less room as the liquid cools? How can you tell?



While performing the experiment on page 53, question the pupils as to the reasons behind each step. Don't overlook #3.

- *Why is it necessary for the flask to be filled?* (We are testing liquid expansion. Air might expand if present and cause us to make an error in observation.)

The answers to the questions are:

1. Liquid rises in the tube.

2. By using the theory of molecular motion. The energy of the water molecules increased, their speed increased, the spaces between them increased, and therefore the volume increased (an interpretation of observation).

3. There is a slow descent in the level of the liquid in the tube as heat energy is given off gradually to less hot surroundings (observation and interpretation).

4. See the answers to #2. This question assumes that your previous answer may not have been complete. Intermolecular space increases in solids and liquids as heat energy is applied and decreases as it is removed. This is also true of gases, but a demonstration of this is the next activity. Base your ideas only on what was observed so far.

The procedure in the experiment on page 54 is self-evident. The only points to be careful about are that the tubing must be the proper length for the size of the flask and that the water placed in the end of the tubing must be a full drop that completely fills the tubing and does not merely run down the side.

The answers to the questions are:

1. The attraction of the water molecules for each other keeps them together in the drop form. As water goes down the tube it compresses the air slightly until the gas pressure equals the downward weight of the drop. The water can go no farther because the water weight and gas pressure are in balance.

2. The water drop rises as gases expand with more force upward. The intermolecular space is increased because of the increased activity of the gas molecules.

Follow-Up: Have pupils give evidence that engineering planning has to take into account that liquids expand when heated. (There are expansion tanks in hot water heating systems; storage jars have a small air space at top; auto radiators have escape valves for too much pressure; etc.)

Heat adds energy to the molecules in a liquid. The molecules bounce against each other faster and harder and take up more room. The liquid expands.

Can you now explain the contraction of liquids when they are cooled?

The molecules of a gas are constantly in motion and are not fixed in a pattern.

EXPERIMENT

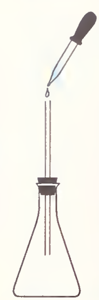
What Happens If Heat Is Added to the Molecules of a Gas?

What You Will Need

flask
eyedropper
one-holed rubber stopper
8-inch glass tubing

How You Can Find Out

1. Insert the stopper and tube into the empty flask.
2. Use an eyedropper to put water into the tube.



Questions to Think About

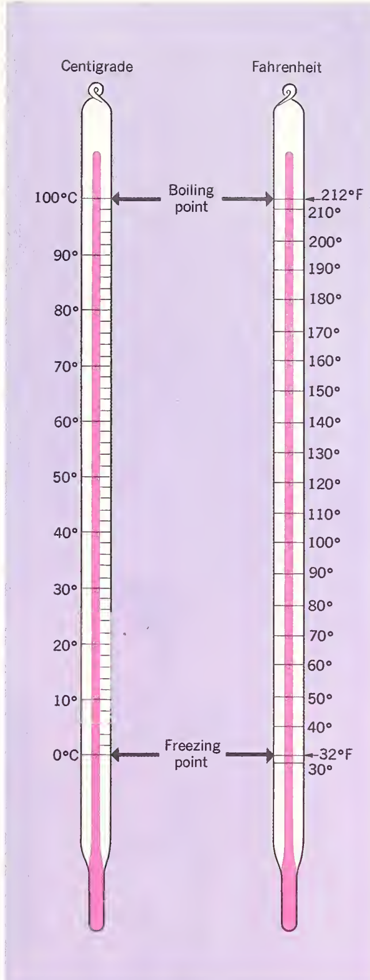
1. Can you explain why the water does not run into the flask?
2. Now heat the flask by holding it in both hands. What happens to the water in the tube? Why?

Heat adds energy to the molecules of a gas, as it does to solids and liquids. They move around faster than they did before. They bounce against the sides of their container. They also move farther apart from each other. Because their arrangement is not fixed, they are more active than the molecules in either a solid or a liquid. The gases expand. The molecules of gas in the flask push against the water in the glass tube, making it rise.

Most solids, liquids, and gases expand when heated and contract when cooled. Expansion is caused by the greater activity of molecules when heated, and contraction is caused by the lesser activity of molecules when cooled.

Measuring Temperature

Man has invented several scales for measuring temperature. On one scale the freezing point of water is labeled 0° and the boiling point of water is labeled 100°. Each degree on the thermometer is 1/100 of the distance between the freezing point and the boiling point of water. This is called a **Centigrade scale**. The Latin word *centi* means one hundred. Another scale is called the **Fahrenheit scale** (FAR-un-hyt). On this scale the freezing point of water is 32° and its boiling point is 212°. Scientists use the Centigrade scale. Can you find out why?

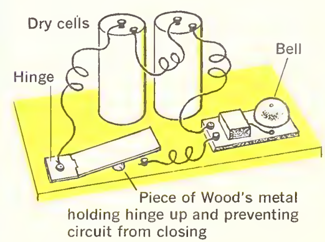


TEACHING SUGGESTIONS
(p. 55)

Background: The obvious differences between the three states of matter can be accounted for in terms of the spacing and mobility of molecules, or submicroscopic particles of matter. The fact that substances expand on heating suggests that molecules are in continual and increasing motion and make more space available for such motion except when confined. Confining an expanding object would cause distortion of a solid or an increase in pressure for a fluid (gas or liquid).

ADDITIONAL ACTIVITIES:

Give your pupils the following assignment: Using what you know about the behavior of substances when heated and cooled, design a fire alarm for near your home boiler. Use only one or two dry cells, bell wire, a bell, metal strips from a food can, and an iron nail or bolt. You may use pieces of wood for support. Draw your design and label it.



TEACHING SUGGESTIONS
(pp. 56–57)

● **LESSON:** What do the markings on a thermometer mean?

Learnings to Be Developed:

Temperature is a measure of the average speed of all the molecules in a substance, compared with water as a standard.

A thermometer is our temperature "yardstick."

A thermometer is reliable because the liquid in it follows the laws of expansion.

There are limits to a thermometer's usefulness.

Developing the Lesson: Obtain an inexpensive thermometer from a "five-and-dime" store. Remove the tube carefully from its calibrated background.

Exhibit this tube to the class and ask:

- *How could we use this to measure temperature?* (We would need some reference points on the tube or on a background.)
- *What points might you suggest?* (Answers will vary, but probably will center around freezing and boiling points of water.)
- *Suppose we wanted our own reference points. What might be used?* (If the class draws a blank, proceed to some suggestions.)

How Does the Thermometer Measure Temperature?

As the sun's rays strike the earth, the earth's molecules become more active. As air touches the warm earth, the motion of the molecules of air is increased, and they strike the thermometer bulb with greater speed. The molecules of the liquid in the thermometer, usually mercury, move more rapidly. They take up more room. The liquid expands. On a thermometer a scale such as the Fahrenheit or the Centigrade scale is marked off carefully to measure how much expansion takes place.

Can you explain what happens when the air becomes cooler?

When the temperature of water is 100° on the Centigrade scale, water molecules have gained so much energy that they are escaping rapidly into the air. A temperature of 0° on the Centigrade scale means that the average speed of the molecules of the water has slowed down so much that they are forming crystals of ice.

Temperature, then, is really a measure of how fast the molecules of a substance are moving. Some molecules move faster than others. Therefore

How does the picture below help you understand what is meant by the word *average?*

temperature is a measure of the *average* speed of the molecules. Does this mean that at a given temperature every molecule is moving at the same speed? Think about the word *average*. If the average height of sixth-grade boys is 4′10″, is every sixth-grade boy that size? Average is a measure of the middle; there will be some measurements above and some below the average.

Temperature is a measure of the average speed of the molecules. But we cannot measure this speed with a stop watch! Often the scientist must use an indirect way to measure something. The thermometer is an instrument used to measure in an indirect way the speed of molecules. Can you now explain what the thermometer is really measuring and why this tells us about the speed of molecules?

You remember that heat is the effect of the movement of all the molecules in a substance. Now you know that temperature is a measurement of the average speed of the molecules in that substance at a given time. Here is an example of the difference between heat and temperature. The Atlantic Ocean contains *more heat* than a cupful of boiling water, because the energy of *all* its molecules is greater than the energy of the few molecules in the cup of boiling water. But the cup of boiling water has a *higher temperature* than the ocean.

Using What You Have Learned

1. Try to think of a liquid you know that does not behave according to what you have learned about heating and cooling. Plan an experiment to show that this liquid is an exception.

2. Thermometers have different substances in them. What is used in your school nurse's thermometer? If there is a large outside theremometer in your town, find out what it contains.

3. For what purposes are the different kinds of thermometers used? What kind of thermometer would have to be used to measure temperatures during the winter in the Antarctic?

- *Let's assume that this is not a problem. What should be our next step?* (Calibration–markings —for future rise and fall readings.)
- *What calibrations or marking units should we use?* (Use the present point as zero. Units above and below can be in inches, millimeters, thicknesses of the cover of a science book—accept any and all suggestions.)
- *What will we call this calibrated scale?* (Anything.)
- *Now that we have our thermometer, to whom would it be useful?* (Only to the class. Explain.)

TEACHING SUGGESTIONS
(p. 57)

Background: The answers to *Using What You Have Learned* are:

1. Water is the most obvious and famous example. It is because water expands as it freezes that its density is less than that of liquid water and it floats.

2. Medical thermometers have mercury in their bulbs. Most everyday thermometers have alcohol.

3. a. To measure body temperatures, measure air temperatures, the temperature of molten metals.

b. Thermometers containing a low-freezing-point liquid, such as alcohol, would have to be used.

TEACHING SUGGESTIONS
(pp. 58–59)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned: This is a summary of the entire unit, with new words in boldface type.

Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390–393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

Explain Why:

1. The average speed of molecules increases. The particles or molecules hit each other with more force. They rebound further from each impact and the spaces between them increase. The total effect is observed as expansion.

2. Thermal energy (in the form of infrared rays) is transferred from the sun to bodies around it (planets) by radiation. This energy is taken in by cooler bodies and the rate of molecular movement increases.

3. If a substance has a molecular structure whose molecules are comparatively slow in their motions they do not take in heat

WHAT YOU KNOW ABOUT

Heat and Molecules

What You Have Learned

All matter is made up of molecules, which are in constant motion. Molecules are the smallest particles of a substance that have all the characteristics of the substance.

Molecules are too small to be seen, but scientists have much evidence that they exist and move. **Diffusion,** or movement of molecules away from a crowded area to an area of fewer molecules, gives some evidence. There is other evidence, such as the dissolving of a solid in a liquid; **conduction,** which causes cool molecules to become warmed when they are touched by heated molecules; and **radiation,** which is the transfer of heat energy to the molecules of a cool object.

Heating causes molecules to move faster and farther apart. Heating may change a solid to a liquid and then to a gas.

Cooling causes molecules of a substance to move slower and to become more fixed in their positions. Cooling may change a gas to a liquid and then to a solid.

Temperature is a measurement of the average speed of the molecules in a substance. Heat is the result of the movement of all the molecules in the substance. Thermometers, such as the **Centigrade** and the **Fahrenheit** thermometers, measure temperature.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

Centigrade scale	diffusion	radiation
conduction	Fahrenheit scale	

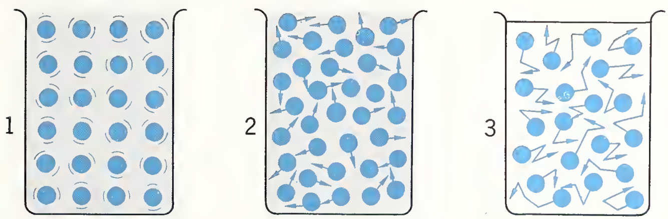
Explain Why

Use your knowledge of heat and molecules to explain why:

1. When air is warmed, it expands.
2. We receive heat from the sun by radiation.
3. Poor conductors are good insulators.
4. Metal handles on cooking utensils become hot.
5. Two thin blankets are warmer than one heavy blanket.
6. A thermos bottle can keep liquids either hot or cold.

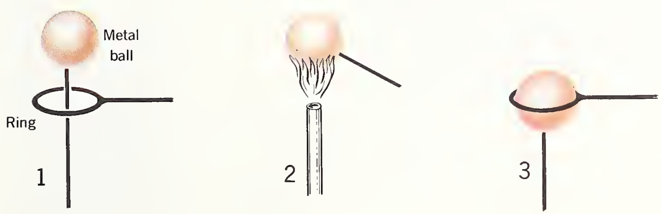
Can You Tell?

Look at the pictures below. Can you tell which jar contains a liquid, which a solid, and which a gas?



What Is Happening?

Can you explain what is happening in the pictures below?



readily by conduction. They can then be used as heat transfer barriers between substances that would transfer heat by conduction more rapidly.

4. Metals are good conductors of heat.

5. Air is a poor conductor. The air space between two blankets acts as an insulator.

6. The vacuum between the two walls cannot conduct heat. The silver lining reflects heat of radiation.

Can You Tell?

1. solid

2. liquid

3. gas

What Is Happening?

1. The ball passes easily through the ring.

2. The ball is heated.

3. The ball will no longer pass through the ring. Heating caused the ball to expand.

TEACHING SUGGESTIONS
(pp. 60–61)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

You Can Find Out: The demonstration will show that different metals do conduct heat at different rates.

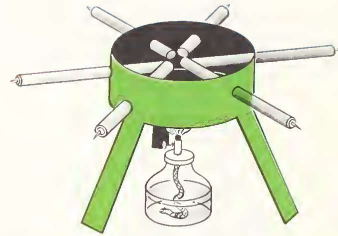
- *Which of these metals would make good cooking utensils?*
- *Have you ever seen pots and pans made partly of one metal and partly of another?*
- *Can you think of a reason for making them that way?*

You Can Make a Thermos Bottle: Both the materials used and the layers of air serve to insulate the liquid in the bottle.

YOU CAN LEARN MORE ABOUT

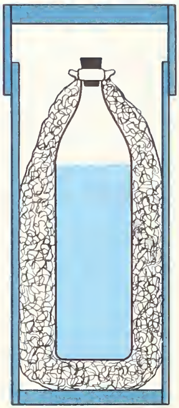
Heat and Molecules

You Can Find Out



Do metals conduct heat at different rates? Get 12-inch-long bars of different metals. Each bar should be of the same diameter. Next, cut a tin can as shown. Then punch holes in the side of the can—one hole for each bar. Insert the metal bars so that they touch at the center of the can. To the outside end of each bar attach a tack or nail with wax. Place a burner under the can holder so that the flame touches the inner edge of each bar equally. In what order do the tacks or nails fall off the bars? What does this show?

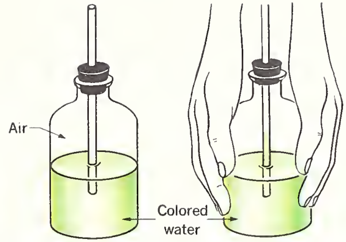
You Can Make a Thermos Bottle



You can use what you know about heat and molecules to make a thermos bottle. Make a cloth bag that will fit loosely around a bottle. Stuff the bag with kapok or cotton filler. Place the bag and bottle in a cardboard cylinder. Attach a string to the cylinder. Drinks can be kept hot or cold in this thermos bottle. Can you explain how?

You Can Make an Air Thermometer

Fill a bottle halfway with colored water. Place a glass tube about two feet long through a one-holed rubber stopper. Place the stopper in the bottle. Place your hands over the upper part of the bottle. Can you explain what happens in terms of the molecules of air?



You Can Read

1. *What Is Heat?* by Theodore W. Munch. Tells about sources of heat, heat and motion, and the importance of heat to man.
2. *Hot and Cold,* by Irving Adler. A more advanced book on the measurement, properties, and uses of heat.
3. *The Wonder of Heat Energy,* by Hy Ruchlis. Tells how various phenomena depend on heat. Suggestions for investigations are given.
4. *Heat,* by Bertha M. Parker, from the Harper and Row Basic Science Education Series. Experiments in the application of heat.
5. *Beginning Science with Mr. Wizard: Heat,* by Don Herbert and Hy Ruchlis. Some excellent experiments are given. The experiments are based on Mr. Herbert's popular television series.

You Can Make an Air Thermometer: The increased molecular motion of the air tends, by conduction, to warm the water. The only direction in which the water is free to expand is up the tube.

Additional Readings:

Heat, by Irving and Ruth Adler (John Day, 1964).

Hot and Cold, by Irving Adler (John Day, 1959).

Your World in Motion, by George Barrow (Harcourt, 1956). Tells how motion affects man through light, sound, heat, and atomic energy.

Solar Energy, by Franklyn M. Branley (Thomas Y. Crowell, 1957). Describes ways in which man is making use of solar energy. Gives an introduction to engines of the future.

Count Rumford, by Sandborn C. Brown (Doubleday, 1963). An excellent paperback story of an American Tory scientist. The "Pathfinder" of this unit.

Matter, Earth and Sky, by George Gamow (Prentice-Hall, 1958). A study of matter and energy.

The Wonder of Heat Energy, by Hy Ruchlis (Harper, 1961). Good diagrams and explanations of many aspects of heat energy.

KEY CONCEPTS

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

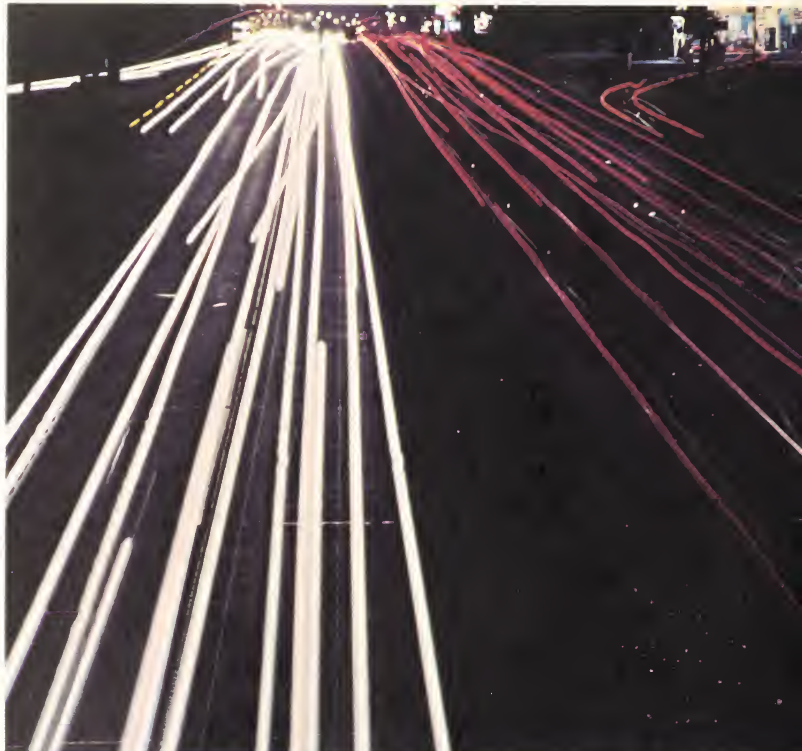
Key Concept 4. All objects in the universe and all particles of matter are constantly in motion; man has discovered and stated the laws governing their motion.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. For an object to move, the forces acting upon it must be unbalanced.
2. An object in motion continues in motion at a constant speed unless some outside force acts upon it.
3. An object at rest remains at rest unless some outside force acts upon it.
4. The acceleration of an object depends on both its mass and the size of the forces acting upon it.

Patterns of light made by automobile lights at night.



3

Other concepts appear under "Learnings to Be Developed" in each lesson found in the Teaching Suggestions.

Objects in Motion

Starting Things

Making Objects Speed Up

Putting an Object into Orbit

Some Other Orbits

5. Acceleration is the rate at which a moving object picks up speed.
6. Force = mass × acceleration
7. Forces are vector quantities.
8. Objects attaining a velocity of 5 mi./sec. may be put into orbit around the earth; at 7 mi./sec. they go beyond the earth to orbit the sun.
9. The moon orbits the earth; the earth, other planets, and comets orbit the sun.
10. All orbiting bodies seem to follow the same laws of motion, implying that the force of gravity operates throughout the universe in exactly the same way.

PROCESSES:

- Observing—Pages 65, 66, 67, 69, 70, 72, 73, 74, 78, 82, 83, 85.
- Experimenting—65, 66, 67, 69, 70, 72, 73, 74, 77, 82, 83, 85.
- Comparing—65, 66, 67, 69, 70, 72, 73, 74, 78, 82, 83, 85.
- Inferring—65, 66, 67, 69, 70, 72, 73, 74, 78, 82, 83, 85.
- Measuring—66, 67, 69, 70, 72, 73, 74, 82, 83, 85.
- Selecting—65, 91.
- Demonstrating—78, 91.
- Explaining—70, 72, 76, 77, 78, 85, 91.
- Hypothesizing—67, 70, 85.

TEACHING SUGGESTIONS
(pp. 64–65)

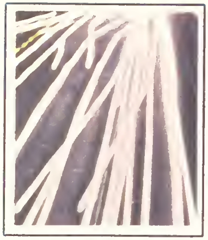
LESSON: How do objects start moving?

Background: With this unit, the pupils will begin the study of motion. Pages 64 through 70 present Newton's First Law of Motion. An understanding of motion is central to an understanding of modern physics. The pupils will have an excellent but intuitive understanding of how objects in motion behave, and you can build on this intuitive understanding quite easily. The difference between an intuitive approach to the subject and that of physics is that physics is concerned with the measurement of motion and with deriving the laws of motion from an analysis of these measurements. As much as possible, therefore, the emphasis should be upon measurement and exact definition.

Learnings to Be Developed: For an object to move, the forces acting on it must be unbalanced.

Developing the Lesson: The concepts of motion and of the necessity of having a force to start an object moving can be developed by asking questions that build on the pupils' intuitive knowledge.

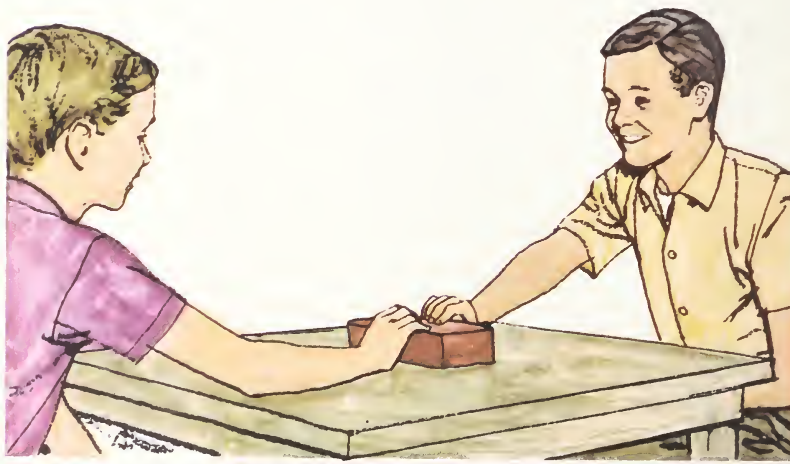
What is motion?

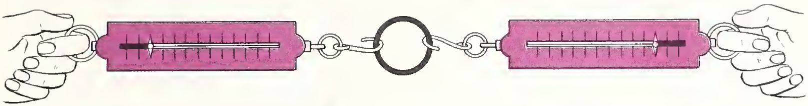


Suppose you have a steel ball on your desk, and you want to make the ball move. How many different ways can you do this? In each way, you must *do* something to make the ball move. Objects do not start moving by themselves. They must be pushed or pulled. A push or pull is called a *force*.

Starting Things

Imagine a tug of war in which the teams are evenly matched. If both teams pull with the same amount of force, the rope does not move. You get the same result if you push hard on a brick from one side while a friend pushes equally hard on the opposite side. The brick does not move. As you can see, forces acting on an object do not always make it move.





See for yourself what happens when equal forces act against each other. Take a strong metal ring and hook two spring balances on it, as shown in the picture. The spring balances measure the amount of force you use. Now pull on the ring in one direction with a steady force of five pounds. Ask a classmate to pull on the ring in the opposite direction with a steady force of five pounds. Does the ring move?

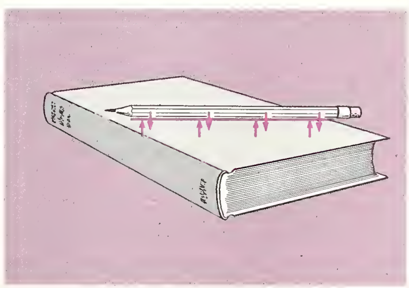
You could do many activities such as this and you would get the same result. An object at rest does not move if the forces on it are equal in size and come from opposite directions. These forces—forces acting on an object so that its state of rest or motion does not change—are called **balanced forces.**

Now try an activity in which you have your classmate pull with a steady five-pound force while you increase your force on the ring. What happens to the ring?

To make the object move, then, the forces acting on it must not be balanced. Somehow the balance of forces must be *upset.* One way of doing this is to change the size of one of the forces. In the metal ring experiment, you *increased* the size of one of the forces. Could you also make the ring move by *decreasing* one of the forces? Plan an experiment to find out. Perform your experiment. What were the results?

There are forces acting on all objects. A pencil resting on a book has forces acting on it. There is a downward force of gravity on the pencil. There is also an upward force exerted by the book on the pencil. The forces are equal and opposite. The pencil does not move.

How could you make the pencil move downward by reducing or removing one of the forces?



How do objects start moving in the first place?

Most of the reasons will be practical—automobiles start to move because you turn on the engine, balls start to move through the air because you throw them or hit them with a bat, etc. Of course, behind all the reasons is the idea that a force is necessary. This is universally true. After the pupils have learned that all the reasons they have mentioned are examples of forces, you can develop the idea of balanced forces. Here you can make use of vector diagrams on the chalkboard. The two boys in the illustration on page 64, for example, can be represented by two vector arrows. The resultant will, of course, be zero, which confirms the intuitively obvious fact that if the two boys push with an equal force, the brick will not move. The examples on page 65 can also be illustrated by vector diagrams to show what happens when all the forces are balanced and what happens if there is an imbalance of forces.

ADDITIONAL ACTIVITIES:

If you have several spring balances available, you can conduct experiments in which three, four, or more pupils pull on a ring with equal forces and then with unequal forces.

TEACHING SUGGESTIONS
(pp. 66–68)

● **LESSON:** Why do moving objects continue to move?

Background: This section continues to develop the pupils' understanding of motion. Once they appreciate that objects move because of forces, the points to be taken up are why objects continue to move and why they stop. The pupils will intuitively understand that any object in motion eventually slows down and stops, without exception, unless a force is continually applied to the object. To use automobiles as an example, the pupils are aware that the driver must continually press down on the accelerator to keep the automobile in motion. If they are riding a bicycle, they must continually pedal if they want the bicycle to keep moving. As mentioned in the text, this is the common-sense Aristotelian view of motion. Galileo maintained, and this is the view of modern physics, that an object in motion tends to remain in motion, and it comes to a stop only because an outside force compels it to stop. The issue is whether the natural tendency of objects is to stop or to remain in motion.

Learnings to Be Developed:

An object in motion continues in motion at a constant speed unless some outside force acts upon it.

Objects Keep Going

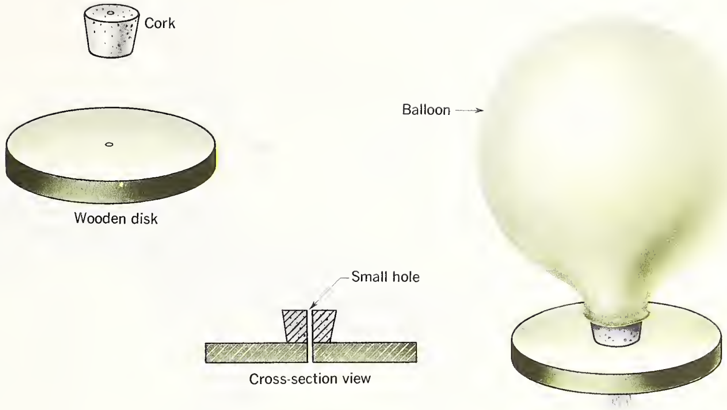
Scientists have always been interested in what keeps a moving object going. Galileo was the first to say that a moving object will continue to move at a steady speed and in the same direction as long as no force acts on it. This means that a sled that is coasting will keep on moving at the same speed unless some force acts on it. The same is true of a rolling skate or any moving object. But you know that objects do not keep going. They always stop. A coasting sled stops moving forward, even on level snow; otherwise the ride would last forever. A skate stops rolling, or you would lose a skate every time you started one going. What forces act on a moving object to stop it?

Forces that you cannot see may stop an object. These are **frictional forces** (FRIK-shun-ul), caused by the rubbing of one object against another. If you slide a book across a table, frictional forces from the table top act on the book to slow it down. Soon the book stops. Friction between a sled and snow stops the sled. Friction between a skate and pavement stops the skate. The frictional force opposes the motion of the object.

If you want to keep an object moving, you must apply a force that is equal to the frictional forces. If you can remove the frictional forces, you can keep an object moving at a steady speed as long as outside forces do not act on it. For example, a puck, or wooden disk, keeps moving on ice at a steady speed for a great distance once it is started. Can you tell why?

The model on the next page greatly reduces frictional forces. Air escaping from the balloon flows beneath the wood. Thus the wood floats on an air cushion. You can build such a device and set it in motion across a smooth, level floor or table. Blow up a balloon, cap it tightly to the cork, and push the wooden disk gently. Does the disk seem to move in a straight line? Does it seem to move at a *constant,* or steady speed?

Constant speed means that the disk moves the same distance during the first second as during the second, the same distance during the second second as during the third, and so on. Measure the motion of the disk to check for constant speed. You will need a device to measure equal **time intervals** (IN-ter-v'lz), and a method for measuring distances traveled. A pendulum clicks off equal time intervals when it swings by the lowest point. Set up a pendulum. Have one person rap the desk with a ruler every time the pendulum weight is straight down. Each time he raps, mark the position of the



How does this model show you one way to reduce frictional forces?

disk. After several markings, measure the distances between marks. Are the distances equal? Did the disk move at a constant speed?

The ancient Greek scholars did not recognize frictional forces. Aristotle, for example, thought that an object keeps moving only if a force is steadily applied. He also thought that it was natural for objects to stop moving. Notice the difference between his ideas and those of Galileo. Galileo thought than an object keeps moving once it is started and *stops* only when frictional forces act on it.

Does Aristotle's idea seem to fit your observations? The moving objects that you see around you stop moving after a while if no force acts to keep them going. You do not start moving on roller skates and then coast forever on level ground without using more force. If you knew nothing about friction between your skates and the ground, Aristotle's idea would seem reasonable.

The forces acting on a steadily moving object are balanced. When the balance of forces is upset, the object may come to a stop or speed up. One way to upset the balance is to add a force, such as frictional force, that is opposite to the direction of the motion. But what happens if the unbalanced force is not *exactly* opposite to the direction of motion of the object? You can find out. Use the balloon disk

An object at rest remains at rest unless some outside force acts upon it.

Developing the Lesson: You might begin with the pupils' intuitive understanding of motion and build on that.

- *Is it natural for objects in motion to continue moving or to stop?*

The idea can gradually be developed that in all the examples the pupils mention, an outside force can always be found that causes the object to stop. This force is a frictional force. Point out that it is only because we are so used to having friction slow down and stop moving objects that we fail to appreciate its importance.

- *Imagine a world without friction. How would you behave?*

They couldn't walk (it would seem as if they were walking on polished ice), turn door knobs, stop an automobile or bicycle, or lift a knife or fork.

You can obtain the air puck described on page 67 from a scientific supply house. Make certain that the opening in the puck releases the air slowly and steadily and with just enough force to overcome the frictional forces.

TEACHING SUGGESTIONS
(pp. 68–69)

LESSON: If a weight falls from the top of a moving vehicle, does it move straight down or does it continue to move forward also?

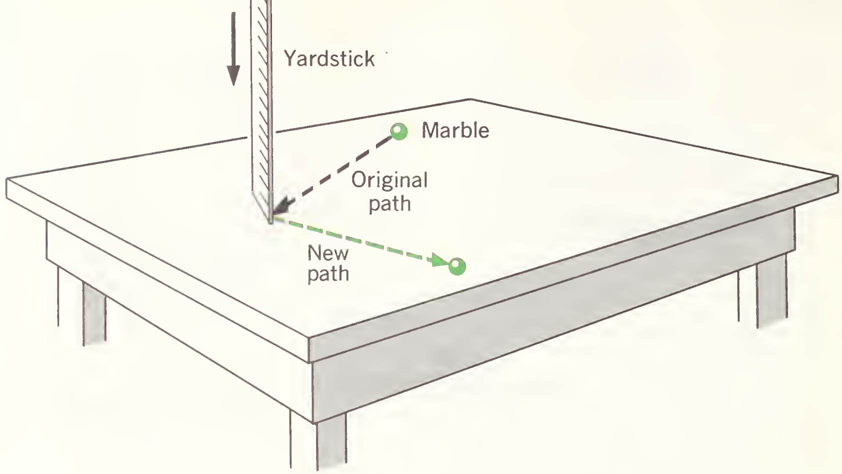
Background: This is a continuation of Aristotle versus Galileo. The Aristotelians believed that if an object were released from a moving vehicle, it would fall straight down. It would appear to move backward relative to the vehicle. Galileo claimed that the object would continue to move forward, appearing to move straight down relative to the moving vehicle. In the experiment described on page 68, the falling object did, of course, partake of the forward momentum of the ship. This may not seem obvious to the students.

Emphasize that an object being carried, on a ship or in the hand of a student, has its own forward motion, which will continue even after the object is released.

Learnings to Be Developed: Objects released from moving vehicles continue to move in a forward direction.

Developing the Lesson: Review the story of the experiment tried on board the moving ship.

- *What do you think was the result of the experiment?*



What happens when you apply to the marble a force that is not opposite to the direction of motion of the marble? How else might you show what would happen?

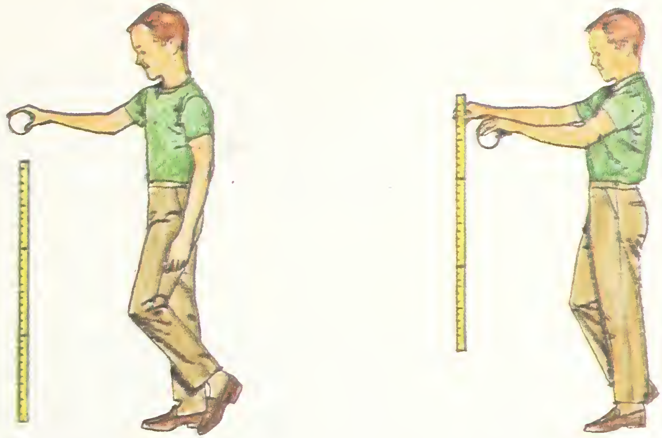
described on page 66, or simply roll a marble along a level surface. Apply a force on the disk or marble that is not opposite to the direction of motion. What happens?

Galileo and the Ship's Mast

Galileo wanted to demonstrate that an object keeps moving even though a force does not continue to act on it. In having this idea, he was one of the first to differ with Aristotle.

Imagine that you are coasting along in a car with the windows closed. You are holding a rubber ball directly over your head. Suddenly you let the ball go. Where would it land? In Aristotle's view, the ball would land *behind you*, because no force acts on the ball once it is released. If this were true, it would mean that a person standing outside the car would see the ball fall straight down. It would also mean that to a person riding forward, the ball would appear to fall backward.

In Galileo's time, scientists thought of doing this experiment on a ship. If the ship were *not* moving and a heavy object were dropped from the top of the mast, the object would land at the base of the mast. But Galileo said that even if the ship were moving, the object dropped from the top of the mast would land in the same spot.



These two pictures show the correct way to release the ball when doing each part of the activity described below. You will need an observer for the activity.

You can try a simple activity to demonstrate Galileo's idea. Set up a yardstick in an up-and-down, or vertical, position. Take a ball in your hand. Walk along holding the ball, and release it just as you pass the stick. Be sure you do not throw the ball. Just let go. Have your friends observe the path of the ball using the yardstick as a background against which to view the ball's motion. Try this several times to be sure of the ball's path.

Now try this. Walk along with the ball and carry the yardstick with you, holding it in a vertical position. Try to walk at a constant speed. Release the ball from near the top of the yardstick. Have your friends observe the ball's motion with the yardstick as the background for the observation.

Newton's First Law of Motion

Isaac Newton, an English scientist in the seventeenth and eighteenth centuries, stated the law of motion that summarizes the ideas in this section. Newton said that if *no* outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed. This statement of Newton's about the motion of objects is called the **First Law of Motion.**

• *Why do you think that is what happened?*

Even if their answers are correct, ask each pupil the reasons for his answer. The experiments described on page 69 can then be tried to see who is right.

Follow-Up: Variations on the experiment described in the text are possible, though with some difficulty. The difficulty arises because a certain velocity will have to be achieved before the forward, parabolic fall of the ball will become apparent. One would need a large wagon on which is mounted a tall pole, so that the pupils could observe both that the ball would fall at the foot of the pole when it was released and also that, relative to outside observers, the ball followed a parabolic path in its fall.

An alternative is to have some of the pupils attempt a series of experiments at home using a clothesline and a basket on the clothesline, arranged so that a ball will fall from the basket while the basket is in motion.

TEACHING SUGGESTIONS

(p. 70)

Background: The answers to *Using What You Have Learned* are:

1. The disk will reverse its direction of motion.

3. The motion of the object will be unchanged, except for the eventual effects of friction.

4. Since the arrow was moving forward, it pushed air aside as it did so and left a vacuum behind it. The air rushed from the front of the arrow to the back of the arrow, pushing the arrow forward as it did so.

Note: In questions such as 4, the practice of imagining is not a game. It is a good habit to get out of a usual frame of reference once in a while. Follow up this type of questioning by asking if their explanation fits what they observed, not what they "know."

Using What You Have Learned

1. For this experiment use the balloon disk described on page 66. Set it moving slowly—as slowly as you can. Exert a force on it that is just enough to stop the motion. Now start it moving slowly again. Exert a force in the same direction as the one you exerted before but greater than the first force. What happens?

2. For this experiment use a small, strong metal ring like the one shown in the picture at the left. Tie four pieces of rope to it. Have one person hold each rope. Have each person pull on his rope at the same time in such a way that the ring does not move. See how many different positions the four people can pull from without moving the ring. Describe the forces exerted on the ring in each case.

3. An object is moving at a constant speed. A force is exerted in the direction of the object's motion. At the same instant an equal force is exerted in the opposite direction. What happens to the motion of the object?

4. Imagine for a moment that you believe, as Aristotle did, that an object keeps moving *only* if a steady force is applied. How would you explain the motion of an arrow through the air after it is shot, or of a ball thrown through the air after it is released? In both cases, a force is used to *start* the object in motion. But in both cases the object *keeps* moving for a short time.

Aristotle thought he knew of a constant force that might keep the objects moving. He developed an explanation of this motion that fitted his ideas. Can you? Find out about Aristotle's explanation of the motion. How would you go about finding out about Aristotle's explanation? What sources would you use? How does Aristotle's explanation compare with the one you developed? What do you think makes an explanation a good one?

Making Objects Speed Up

If you apply a large enough force to an object at rest, the object starts to move in the direction in which the force is applied. You have seen this happen and made this happen many times. Push a book, and the book starts to move in the direction of the applied force.

When you swing a bat at a baseball, the ball moves in the direction of the force applied by the bat. When you kick a football, it sails into the air in the direction in which your foot was pointed. What are some other examples of how you make objects move?

TEACHING SUGGESTIONS
(p. 71)

LESSON: Why do objects speed up?

Background: Pages 71 through 77 develop Newton's Second Law of Motion, in which he describes the effect of a constant force acting on an object and how this force acting upon the mass of the object results in changes in motion.

Learnings to Be Developed: The acceleration of an object depends on both its mass and the size of the forces acting on it.

Developing the Lesson: The four illustrations on this page show a variety of objects that are or are about to be in motion. These objects have different masses. They also have different forces acting on them. Ask the class about these four pictures.

- *How are these pictures all alike?*
- *How are they different?*

Emphasize mass and the size of the forces until your pupils understand that both affect the motion of an object. The pupils will probably need a good deal of guidance at first.

TEACHING SUGGESTIONS
(p. 72)

Background: In this experiment the pupils will discover that if the same force is exerted upon different masses, the greater mass will be more difficult to move, while the lesser mass will be easier to move. Also, the greater the force exerted upon a mass, the greater the acceleration of that mass (i.e., the mass will speed-up more rapidly). The experiment will be most instructive if a string is tied around the bottom book and a spring balance attached to the string to measure the force required to keep the books moving. The difficulties are overcoming the initial friction of the books and maintaining a constant pulling force.

The answers to "Questions to Think About" are:

1. The greater an object's mass, the harder to move it.

2. If forces are equal, an object with a greater mass is more difficult to start than one of less mass.

3. It suddenly starts to move as the starting friction is overcome.

4. The greater the force exerted originally, the greater the subsequent motion of the object.

How Can an Object Be Speeded Up?

What You Will Need

10 books of the same size

How You Can Find Out

1. Set up four piles of books, the first pile with one book, the second pile with two, the third with three, and the fourth with four.
2. Using one finger, exert a force on the bottom of the pile containing two books. The force should be just large enough to start that pile moving. Practice exerting that same amount of force on the pile several times so that the pile moves in exactly the same way each time. If you tie a spring balance to the books, you can measure the force required to move them.
3. Exert the same amount of force you used on the two-book pile on each of the other piles. Push on the bottom book each time. Notice what happens to the pile containing one book, then that with three books, then that with four books.

Questions to Think About

1. Each pile of books has a different mass. The four-book pile has a greater mass than the three-book pile. The three-book pile has a greater mass than the two-book pile. But you use the same amount of force in trying to move each mass.
   What is the relationship between how readily you can start an object moving and the mass of the object?
2. If you keep the force equal each time, which object is started more easily, one with a large mass or one with a small mass?
3. Exert a slight force on the two-book pile. Next exert a slightly greater force, then a still greater force, then one still greater. What happens to the object as you add greater and greater force to start it moving?
4. How is the motion of the object related to the size of the force exerted to start it moving?

Forces on a Moving Object

What happens to a *moving* object if you add a force in the same direction as the motion? For this activity use an object that will have very little friction with the surface on which it is moving. Objects such as a roller skate, a marble, or the balloon puck will work well for this activity. What kinds of surfaces do you think will work well?

Start the object moving. While it is moving, exert a force on it in the same direction as the motion by giving the object a sudden push. What happens to the speed of the object?

If you add a force to a moving object, the object speeds up. But so far you have added a force for only an instant, by one quick push. What happens when you add a force for a longer time?

TEACHING SUGGESTIONS
(pp. 73–74)

LESSON: What happens if you add a force to a moving object?

Background: Pages 73 through 75 introduce the idea of acceleration, which is the rate of change of the velocity of a moving object. The idea of a constant force inducing a constant acceleration may seem unusual to the pupils, but the examples in the text and the experiment on page 74 should make this concept clear to them. At first, discrete increases in force are discussed, since it is more obvious that a sudden push will increase the velocity of a moving object. After this point has been grasped, a constant force is discussed.

Learnings to Be Developed: A force acting on a moving object in the direction in which the object is moving increases the velocity of the object.

Developing the Lesson: This concept should be intuitively evident to the pupils. They will have had experience of this fact in innumerable ways all their lives. However, the concept should be made in class so that the sequence of ideas is developed in an orderly way.

- *Can you give examples of how objects act when a force sufficient to move them is suddenly applied to them?*

- *Can you give examples of how objects act when a steady force sufficient to move them is applied to them?*

The experiment on page 74 is simple and straightforward. Points to keep in mind are that the pupils should exert a constant force on the roller skate and that it should move in a straight line. There should be room for them to pull the skate a considerable distance. A paved sidewalk that runs the length of the room may be used; otherwise the pupils won't have distance enough to accelerate the skate over a long enough period for easy observation.

Background: The answers to the questions are:

1. It maintains a constant velocity.

2. The skate accelerates.

3. Yes, until the point is reached where friction is equal to the force applied.

Follow-Up: In the discussion following the experiment, the main point that the pupils should have noticed is that even though they pulled upon the skate with approximately the same force the entire distance, the velocity of the skate increased continually.

What Happens If You Exert a Constant Force to a Moving Object?

What You Will Need

rubber band roller skate

How You Can Find Out

1. Attach the rubber band to the roller skate, as shown in the diagram. Exert a force on the roller skate by pulling on the rubber band. The length of the stretched rubber band gives you an idea of the amount of force you are using.
2. You must use a constant force. Therefore, the rubber band must be stretched to about the same length throughout the activity.
3. Start pulling the skate with the rubber band stretched just a little. Then keep it that way by continuing to pull with the same amount of force.

Questions to Think About

1. What happens to the skate if you keep exerting the same force?
2. What happens when you increase the force?
3. Does a very small force exerted constantly on a moving object make the object speed up continuously?

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Tell where friction occurs in each picture. What does friction do in each of the pictures shown above? How is the friction overcome in each situation?

You have read about velocity and how it changes. The velocity of a moving object changes when the speed or the direction of the object changes. When the velocity of an object changes, the object is said to accelerate. In the activity showing constant force on the roller skate, the skate accelerated.

Since a constant force speeds up a moving object, you would expect things to go faster and faster just by applying a steady force. But you rarely see such continual acceleration. If you are riding a bike on level ground and exert a constant force, you accelerate for a short time. But after a while the constant force does not make the bicycle go faster. If it did, you would ride faster than the fastest jets after a while.

To find the explanation, we must think again about frictional forces. There is friction between the tires and the road, and between the chain and the axle. Friction increases as speed increases. In fact, friction becomes so great that you must exert a strong force just to keep going. Only in a frictionless world would you go faster and faster on your bicycle just by exerting a small, steady force.

*The jet aircraft overcomes air friction with the thrust developed by its engines.
**The friction between the car's tires and the road is useful: it gives the car traction, which enables it to move forward along the road.
***The friction between the runners' shoes and the track is also useful, since it enables them to get traction and so run faster.

TEACHING SUGGESTIONS
(p. 75)

- **LESSON:** What limits the speed of accelerating objects?

Background: This page concludes the introduction to accelerating forces by returning once again to the concept of friction. As every pupil who has ridden a bicycle knows, there comes a point when no matter how hard you pedal you don't go any faster. There appears to be a limit to acceleration, and this limit is the increase in frictional forces that accompanies increases in acceleration.

Learnings to Be Developed: Friction limits the amount of acceleration that a moving object can undergo, no matter how large the accelerating force.

Developing the Lesson: The discussion can be based on the preceding experiment and on the pupils' practical experience with bicycles (as mentioned above) and with other moving vehicles.

Background: The jet aircraft encounters air friction, which holds its speed down. The automobile encounters air friction; also there is friction between its tires and the road. The runners also encounter air friction as they start to move forward, as well as the friction between their shoes and the track.

TEACHING SUGGESTIONS
(pp. 76–77)

● **LESSON:** How is acceleration measured?

Background: The important point to be made here is that acceleration is a *rate* of change. When an object accelerates from one velocity to another it is necessary to know how much time it took before one can state the *rate* of acceleration. Mathematically, the relationship is very simple:

acceleration = mass × force

Learnings to Be Developed: Acceleration is a rate of change that depends on the mass of the object and the force applied to the object.

Developing the Lesson: The best way to make the relationship among acceleration, force, and mass clear is to work examples on the chalkboard as you explain the relationship. Work the sample problems carefully, having the pupils volunteer what the next steps are. Change the values in the problems, and also construct problems using metric measures.

In problem 1, the skater accelerates 3 miles per hour per second. In problem 2, the automobile is traveling at 20 miles per hour after 10 seconds.

Measuring Acceleration

You can measure the acceleration of a moving object. Imagine that you are riding a bicycle at a steady 5 miles per hour for 10 minutes. You are not speeding up or slowing down. Your acceleration is 0.

Next, suppose that you are riding at 4 miles per hour but speed up to 10 miles per hour after 1 minute. The increase in speed from 4 miles per hour to 10 miles per hour is 6 miles per hour in 1 minute.

A car is going 15 miles per hour. In 10 seconds it speeds up to 35 miles per hour. The acceleration is 20 miles per hour in 10 seconds. To find how much the car accelerates each second, you divide 20 by 10, which is 2. The *average* acceleration is 2 miles per hour each second. We say that the average acceleration is 2 miles per hour per second.

You are riding a bicycle at a slow 2 miles per hour. You speed up to 18 miles per hour in 4 seconds. The acceleration is 16 miles per hour in 4 seconds. To find the average acceleration each second, you divide 16 by 4. The acceleration is 4 miles per hour per second.

Here are some problems:

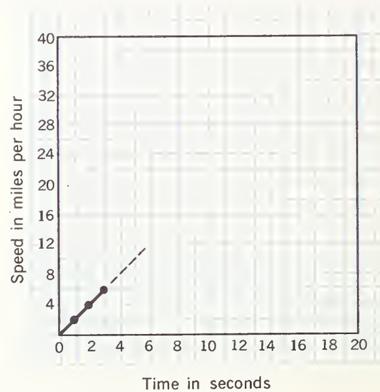
1. A speed skater going at 5 miles per hour speeds up to 20 miles per hour in 5 seconds. What is his average acceleration each second?

2. An automobile accelerates at a rate of 2 miles per hour per second. How long does it take the automobile to accelerate from rest to a speed of 20 miles per hour? Complete the graph below to find the answer.

Force, Mass, Acceleration

You have learned that the acceleration of an object in a certain direction depends on the size of the force, the direction of the force, and the mass of the object.

Complete this graph using the information given in problem 2. Be sure you do not write in the book. Instead, copy the graph in your notebook and complete it.



The mathematical relationship among force, mass, and acceleration worked out by Newton is called the **Second Law of Motion.** Some examples of this relationship follow.

1. If you double the force on a certain mass, the acceleration doubles.

2. If you use the same force on a mass twice as great as another mass, the acceleration is only one half as much for the greater mass.

3. To get the same acceleration for a mass twice as great as another mass, you must exert twice as much force as you would exert on the smaller mass.

Using What You Have Learned

1. If you push a wagon with twice as much force as your friend pushes a wagon of the same mass, how much more is your wagon accelerated than your friend's wagon?

2. A freight train with one engine pulls twenty loaded coal cars. It accelerates at 5 miles per hour each minute. A second engine is hooked on and pulls with the same force as the first engine. What is the new acceleration?

3. Imagine exerting on a heavy adult running away from you the same force you exert on a child running away at the same speed. What difference will there be?

4. Hook a spring balance to a roller skate and try to pull with a steady force. Notice the acceleration. Now firmly tie a brick to the skate. Pull with an equal force. Is there a difference in the acceleration? Why?

5. Try to add a second brick to the skate. Tie it on firmly. Pull with a force equal to that exerted in Activity 4. What happens? Why?

6. Explain how Newton's Second Law of Motion enables scientists to determine the size of the force that is needed to put a satellite into orbit and to change its direction, speed, and position.

Background: The answers to *Using What You Have Learned* on page 77 are:

1. Twice as much.

2. Ten miles per hour per minute. (The force and therefore the acceleration are doubled.)

3. The adult will be slowed down less than the child. The exact difference will depend on the mass of each, but the mass of the adult can be assumed to be greater.

4. Yes, acceleration is slower, because the mass has increased.

5. The acceleration is about one-half that of the skate in activity 4, because the mass has approximately doubled.

6. Newton's Second Law states that the rate at which the momentum of an object changes depends solely on the forces applied against it. The momentum, in turn, depends on the mass and velocity of the object. Therefore, according to Newton's Second Law, all a scientist need know in order to control the flight of a satellite is its mass and velocity. Knowing them, he can then easily calculate the size and direction of the force that must be exerted on the satellite to change its direction, speed, or position.

TEACHING SUGGESTIONS
(pp. 78–81)

● **LESSON:** How do objects behave when they fall?

Background: The principal physical concept being introduced in this section is that of gravity, or gravitational force. In discussing how gravity acts, an important distinction must be made concerning the distance over which the force of gravity acts. The gravitational force exerted on a falling object increases as the object nears the earth.

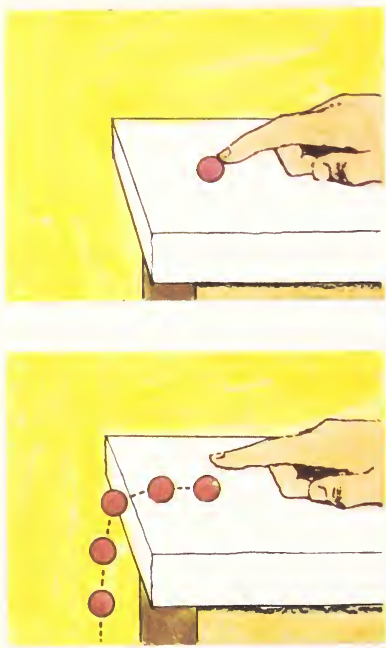
Learnings to Be Developed: The acceleration of freely falling objects is due to the constant force of gravity acting on them.

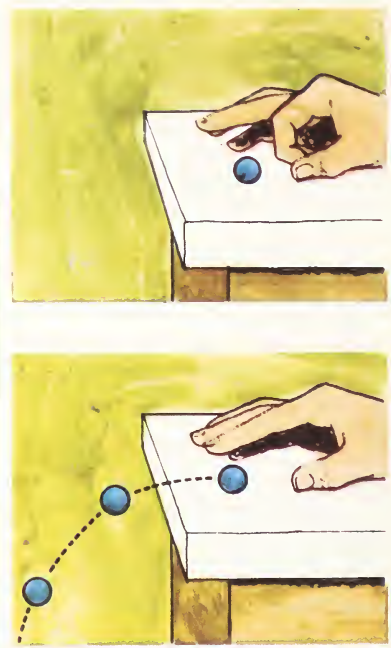
Developing the Lesson: This section can be assigned to be read at home before being discussed in class. In class, you can begin by discussing the visible behavior of falling objects. The illustrations in this text show projectiles follow a curved path when they fall. Do not ask the pupils now why this should be so; the reason will be developed as this section continues. You must plan the discussion so that the pupils realize that two separate forces are being discussed in these pages: the horizontal force that is provided by the flick of the finger and the gravitational force that is suddenly imposed on the ball as it reaches

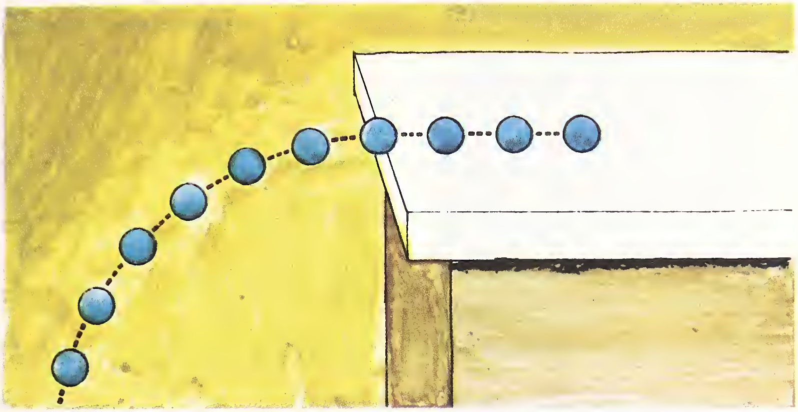
Putting an Object into Orbit

Suppose you were to nudge a marble off the edge of a table. You know that it would fall. The force of gravity would draw the marble toward the earth. But would the marble land near the table or away from it? Draw a diagram to show the path that you think the marble would take.

Now suppose you were to flick the marble off a table straight out into the air. The marble, of course, would again fall to the floor. Where would it land this time? Would it fall just beneath the table top or some distance away? Draw a diagram to show the path that you think it would take.







Observe the path a marble would travel if it were rolling on a frictionless table top.

The first marble had only one motion—downward. But the second marble had two motions—outward and downward. The flick of your finger provided the force to start the marble moving outward. Once set in motion, the marble, like any other object, moved outward at constant speed. (The air exerts some frictional force, but not enough to affect the marble much in this activity.) Constant speed in an outward direction means that the marble moved outward the same distance every second.

The diagram above shows how the marble would travel if it were rolling along on a frictionless table top. The position of the marble is shown at intervals of one-tenth of a second. Notice that the distance traveled in each fraction of a second is the same. This is the motion you expect according to Newton's First Law of Motion, which says that if no new force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed.

But when you flicked the marble off the table, there was downward as well as outward motion. Immediately after it left the edge of the table, the marble was pulled toward the earth by the force of gravity. This force acts in a vertical direction. As you know, the actual direction of movement of the marble was the result of both forces.

the end of the table. What you should concentrate on is the downward motion of the ball after it drops off the end of the table. The photograph on page 80 shows the path of a falling ball, which you can take as typical. Have the pupils measure as carefully as they can the distances between successive positions of the ball. Have them calculate, by using the formula given on page 80, the speed of the ball during each time interval. Their figures should show that the ball is accelerating at a constant rate. Therefore it must be subject to a constant force, which is gravity.

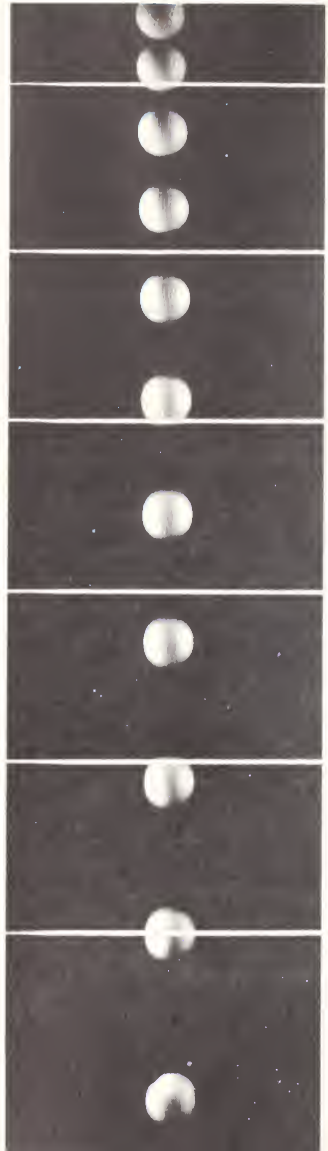
Follow-Up: You can divide the class into groups and set different conditions for the measurement of the falling golf ball. The *rate* of acceleration should, of course, come out the same no matter what figures the pupils use to start with.

○ **ADDITIONAL ACTIVITIES:**

It is comparatively simple to take photographs similar to the one on

page 80 if a 4 x 5 camera with a Polaroid back is available. (Many camera shops will rent such a camera for about $5–$10 a day.) Polaroid manufactures a special transparent film for the 4 x 5 back that is extremely fast. Load the film in the Polaroid back, place the camera on a tripod, and in front of the lens place an ordinary fan. (If a Stroboscope is available, all the better. Take the exposures by the light of the Strobe flashes.) Opposite the camera, in front of a plain white backdrop, the pupils can bounce balls, drop balls from various heights, or shoot projectiles out of a toy cannon. Open the camera lens for a time exposure, start the fan or the Stroboscope (to obtain a series of exposures on the same film), and have the pupils do their tricks. The Polaroid film can be developed immediately and projected on a screen for the pupils to analyze. They can judge the effect of dropping the same ball from varying heights, or the effect of differing forward motions on the arc of the falling ball.

For greater precision, the backdrop used can be marked off accurately in squares so that the pupils can make quantitative measurements and graph the results.



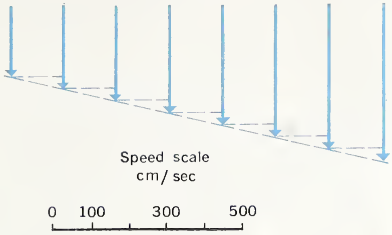
Here is a series of photographs, taken at equal time intervals, of a falling golf ball. The time interval between each photo and the next is 1/30 second. The white lines are six inches apart. Notice that the ball is accelerating as it falls. How far does it fall in the first fraction of a second? In the next? If the distance is greater for the same period of time, then the speed must be greater.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

The ball is speeding up at a steady rate. We can say that it is accelerating uniformly. For every interval of time the amount of acceleration is the same.

According to Newton's Second Law of Motion, things speed up uniformly only when there is a constant force. Gravity is the force making the object fall, and the force of gravity is constant. It always exerts a steady force on any object near the surface of the earth.

The outward force and the downward force on the marble or on the golf ball act independently of each other. The outward force does not change the downward force, and the downward force does not change the outward force.



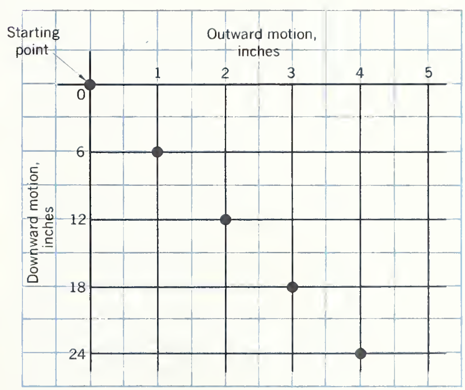
Look at the diagram above. It illustrates, as does the photograph on page 80, the motion of the falling golf ball. We can study the motion of the ball by finding out (1) the size of the force that acts on the ball and (2) the direction of the force acting on the ball during each time period. We can measure the distance the ball falls during a given time period by measuring between the golf balls on the photograph, and then we can divide this distance by the time period. This will give us the length of the velocity vector. The direction of the velocity vector is the direction the ball moves from one photograph to the next. The diagram above represents the distances the ball falls between flashes of the camera. The spaces between the white lines shown on the photograph on page 80 represent 6-inch distances, and the time between flashes is $\frac{1}{30}$ of a second. What do you notice about each velocity vector?

Can you tell why centimeters were used in the scale rather than inches?

A Graph That Can Never Be

Suppose that gravity did not accelerate objects and that sizes of downward vectors did not change. One short push would start the ball downward. Let us see where the golf ball would be after each fraction of a second.

In this graph of an imaginary situation, the dots represent the positions of the ball at the end of equal time intervals. At the end of the first fraction of a second the golf ball would have moved out one inch and down six inches. At the end of the next fraction, it would be out another inch and down another six inches. What kind of a path would the marble have taken? What would be the shape of the path?



TEACHING SUGGESTIONS
(pp. 81–82)

LESSON: Is there any connection between the forward motion of a falling object and its downward motion?

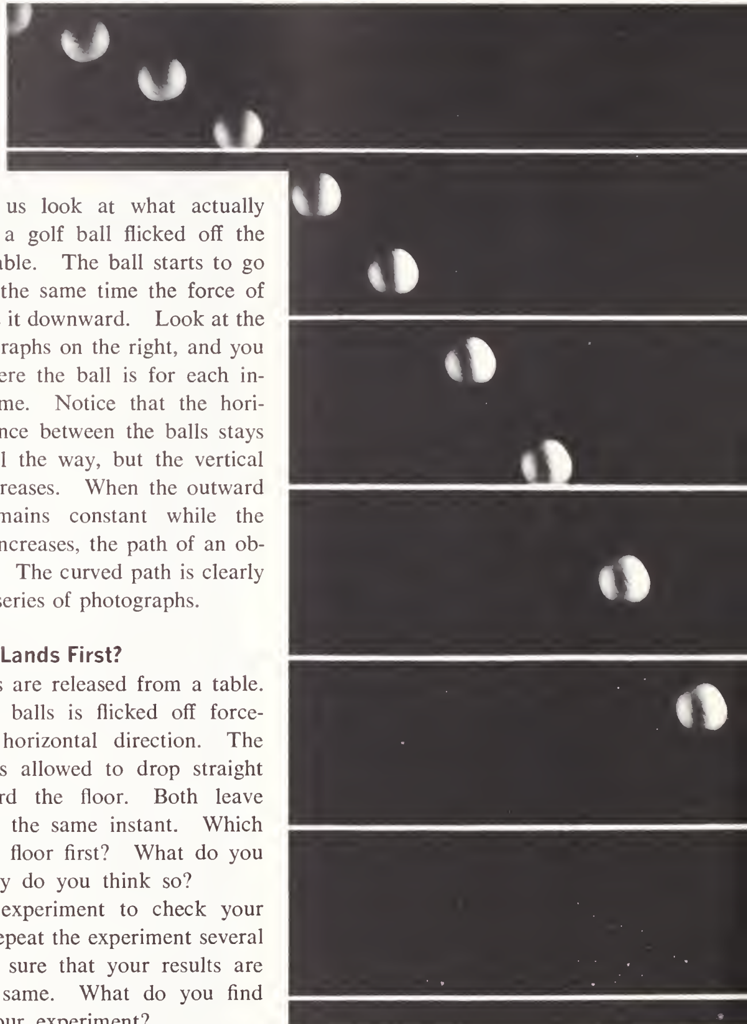
Background: *A Graph That Can Never Be* illustrates how useful it can be to think through the consequences of an imaginary situation. Frequently, a scientist asks himself, "What would happen if . . . ?" Thus, it may be useful to imagine force of gravity in the center of the earth, even though no one will ever be there. Similarly, some scientists develop the consequences of flight in a uniform atmosphere, rather than in an atmosphere that rapidly thins out. It sometimes happens that the "imaginary" situation is in fact a real one at some location in the universe. Motion such as described by this graph actually exists in the absence of gravitational forces—that is, in space.

Page 82 concludes the introductory material on the behavior of falling bodies. The illustration is a "side view" of the illustration on page 80, showing the motion of a ball under the combined forces of gravity and the forward flick of the hand. In discussing the experiment in which the two balls are released at the same time, the

fact that the two forces are completely independent of each other should be driven home. Although the two balls have different forward velocities, the effect of gravity on them is identical; therefore, they will travel vertically in exactly the same time.

Learnings to Be Developed: The forward and downward motions of a falling object are completely independent.

Developing the Lesson: Review briefly the facts discovered on page 80 concerning the behavior of a falling ball—that because it accelerates at a constant rate there must be a constant force acting on it, and that this force is gravity. Then go on to say that the pupils will now learn why the path of the ball in the illustration on page 81 is curved. Have the pupils measure separately both the forward motion of the ball and the downward motion of the ball. They can then see that the forward velocity is constant, while the downward velocity increases. You can conclude by discussing the question raised on the bottom of the page, "Which ball lands first?"



Now let us look at what actually happens to a golf ball flicked off the edge of a table. The ball starts to go out, but at the same time the force of gravity pulls it downward. Look at the flash photographs on the right, and you will see where the ball is for each interval of time. Notice that the horizontal distance between the balls stays the same all the way, but the vertical distance increases. When the outward velocity remains constant while the downward increases, the path of an object *curves*. The curved path is clearly seen in the series of photographs.

Which Ball Lands First?

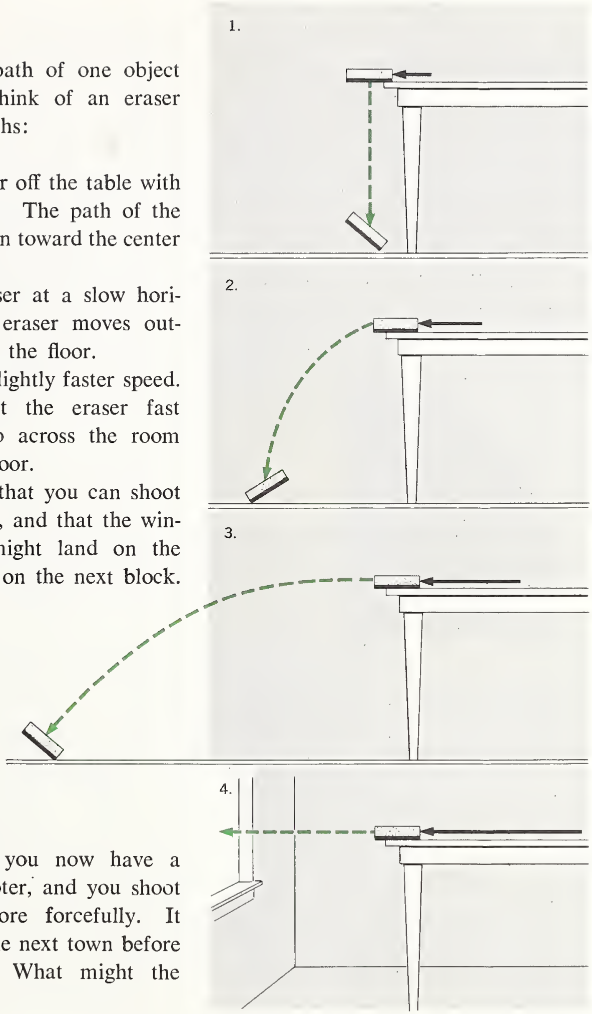
Two balls are released from a table. One of the balls is flicked off forcefully in a horizontal direction. The other ball is allowed to drop straight down toward the floor. Both leave the table at the same instant. Which one hits the floor first? What do you think? Why do you think so?

Plan an experiment to check your answer. Repeat the experiment several times to be sure that your results are always the same. What do you find out from your experiment?

Orbits

An orbit is the path of one object around another. Think of an eraser in the following paths:

1. Push the eraser off the table with *no* horizontal speed. The path of the eraser is straight down toward the center of the earth.
2. Shoot the eraser at a slow horizontal speed. The eraser moves outward before striking the floor.
3. Shoot it at a slightly faster speed. If you really shoot the eraser fast enough, it might go across the room before striking the floor.
4. Now imagine that you can shoot the eraser still faster, and that the window is open. It might land on the school yard or even on the next block.



5. Imagine that you now have a powerful eraser shooter, and you shoot the eraser even more forcefully. It might go as far as the next town before striking the earth. What might the path look like?

TEACHING SUGGESTIONS
(p. 83)

LESSON: How does an object go into orbit?

Background: The material up to this point in the chapter should have laid a firm enough foundation for your pupils to understand the sequence of ideas developed.

Learnings to Be Developed: A stable orbit around the earth can be achieved if there is a balance between the forward velocity of a satellite and the rate at which it "falls" toward the earth.

Developing the Lesson: Pages 83 and 84 can be assigned for reading at home. The content of this section should be pretty much self-evident, and you need do little more than summarize it in class. The one point that may cause difficulty is the idea of the earth curving away from the satellite as the satellite perpetually falls toward the earth. If necessary, you can, by drawing a large circle on the chalkboard to represent the earth, review the argument step by step to be sure that the students appreciate the idea that an object can continuously "fall" toward a continuously receding earth.

TEACHING SUGGESTIONS
(pp. 84–85)

● **LESSON:** How much force is required to put a satellite into orbit?

Background: This section continues the development of the concepts originally presented on pages 83 and 84. The main points to emphasize are the enormous force required originally to accelerate a satellite to a velocity of 5 miles per second and the smallness of the force required thereafter to accelerate the satellite to higher velocities. Theoretically, there is no reason that a boy with a water pistol and an unlimited supply of water could not continuously accelerate a satellite that had escaped the earth's gravitational field until the satellite reached the speed of light.

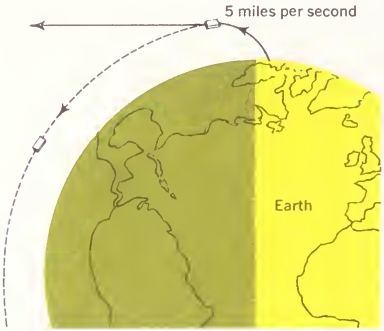
Learnings to Be Developed:

To be put in orbit about the earth, an object must be given a horizontal velocity of 5 miles per second.

At 7 miles per second the object would go beyond the earth's gravitational field and into an orbit around the sun.

Once a satellite has achieved a stable orbit, no additional force is required for it to maintain that orbit.

6. This time imagine that you shoot the eraser at 5 miles per second. The eraser keeps falling to the earth as it did in 1 through 5, but the horizontal speed is so great that the earth curves away from the falling eraser as fast as the eraser falls toward the center. The eraser is in orbit around the earth.



To put an object in orbit around the earth, the object must be given a horizontal speed of about 5 miles per second. The object is first shot straight up to clear the earth's atmosphere quickly. Then the *horizontal* force is applied to put the object in orbit. It does not matter whether the object is an eraser or a rocket. If it is shot out horizontally with a speed of 5 miles per second, it goes into orbit around the earth.

Space Capsules

The earth's atmosphere thins out rapidly as the distance from the earth increases. In fact, one-half the atmospheric volume is under the altitude of 3½ miles. An object traveling in space is far higher than this. Therefore, the frictional forces of air are small, and the laws of motion seem easier to understand.

A tremendous force is needed to accelerate a space capsule so that it clears the earth's atmosphere quickly and reaches a horizontal speed of 5 miles per second. But once this speed is reached and the object is above the atmosphere, only one force continues to act on the capsule—gravity. No fuel is needed to keep the capsule in orbit. The object is pulled toward the earth, but because of the great horizontal speed and the lack of frictional forces to change the horizontal speed, the earth curves away from the capsule as rapidly as the capsule falls.

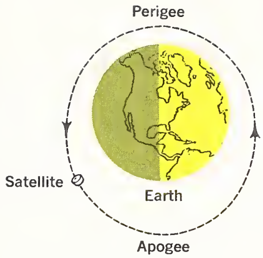
While the capsule is orbiting, only very small forces are needed to change its position. The force of a water pistol is enough to make the capsule tilt. This force is enough to make the capsule accelerate to much higher speeds. Small rockets have enough force to make the object head back to earth.

Most orbits are not perfect circles. They are slightly longer in shape. This

Your pupils could compile a list of artificial satellites that are orbiting the earth. Encourage them to learn as much about them as they can and see if they can find relationships between the purpose of each satellite, the shape of its orbit about the earth and its altitude above the earth. These are chosen for particular reasons. A perfect

shape is called an **ellipse** (ih-LIPSS). The point on the ellipse nearest the earth is the **perigee** (PEHR-uh-jee). The farthest point is the **apogee** (AP-uh-jee).

As you know, many man-made satellites have been sent into orbit around the earth. They have to reach a speed of 5 miles per second, or they will fall back to earth. But if they reach a speed as high as 7 miles per second, they are traveling too rapidly to be in an earth orbit. The capsule then is very little affected by the earth's gravitation. It goes into an orbit around



the sun. Many capsules have reached 7 miles per second, called **escape velocity**, and have entered into orbits about the sun.

Using What You Have Learned

1. Imagine that you are in a space capsule that is falling toward the earth. You hold out your arm and drop a ball. What path will the ball take, as seen by an observer on the ground?

2. What special steps are taken to prevent space capsules from burning up when they re-enter the atmosphere?

3. It is difficult to study the accelerated motion of an object that is falling freely. To "slow" the motion, you can roll the object down a slope. This is what Galileo did in his studies of falling objects. Take a smooth board six feet long and put books under one end to lift the board two inches off the floor. Then roll a smooth cylinder down the slope and mark the position after each second. Figure out a method of marking the position of the cylinder after each second. Compare the distance traveled during the last second to the distance traveled during the first second.

example of a satellite that is falling toward the earth at precisely the same velocity as that at which it is moving horizontally is a communications satellite that is maintaining a stable position about a point over the earth.

Developing the Lesson: Manned space flight is of great popular interest, and you can center the discussion around recent space flights and what they show about the forces necessary to achieve and maintain stable orbits.

TEACHING SUGGESTIONS
(p. 85)

Background: The answers to *Using What You Have Learned* are:

1. The ball will follow exactly the same orbit as the space capsule. To the person in the capsule, the ball will seem to be suspended in space.

2. Their rate of acceleration is slowed down by firing retro-rockets; they take a long, gliding path to minimize air friction heating the capsule; the capsule is designed and built of special materials that direct the heat induced by friction away from the interior of the capsule.

3. In this activity, the board and cylinder should be as smooth as possible to reduce frictional forces. The activity will confirm the fact that the constant force of gravitation causes an object to accelerate constantly.

TEACHING SUGGESTIONS
(pp. 86–87)

Background: Sir Issac Newton, who was born at Woolsthorpe, Lincolnshire, on December 25, 1642, and died in London on March 20, 1727, is undoubtedly the most famous scientist that ever lived, and the most important.

As a boy, Newton lived with his grandparents. He grew up solitarily, interested in mechanical devices, which he constructed himself; he had little interest in school. He was considered dull, in fact. Nevertheless, his schoolmaster recognized his abilities and encouraged Newton's mother to send him to Cambridge instead of becoming a farmer, which she wished. He graduated from Cambridge in 1665, aged 23. In 1669, at the age of 27, he was appointed Professor of Mathematics.

He had by this time conceived most of the ideas that were to make him famous in later years. An outbreak of the plague at Cambridge in 1665 caused him to return to his mother's farm for two years. It was there that he first conceived of the idea of universal gravitation operating throughout the universe.

What did Newton accomplish? He formulated the laws of motion and of gravitation that are studied

PATHFINDERS IN SCIENCE

Sir Isaac Newton

(1642–1727) England

The story is told that one day in 1666, while sitting in a garden, Isaac Newton saw an apple fall from a tree. He thought about falling objects. Why did the apple fall down instead of up? If apples fall down, why doesn't the moon fall down?

Isaac Newton was able to get new meanings from facts. For example, to Newton the apple became the moon. He knew that the moon and other large heavenly bodies seemed to move in regular orbits month after month, year after year. He wondered what force kept them there. Was it the same force that caused the apple to fall from the tree?

Why do the planets go around the sun? Why don't they fly off in straight lines? Perhaps a greater force—the sun's—pulls them out of their straight-line paths. Why does the moon circle the earth?

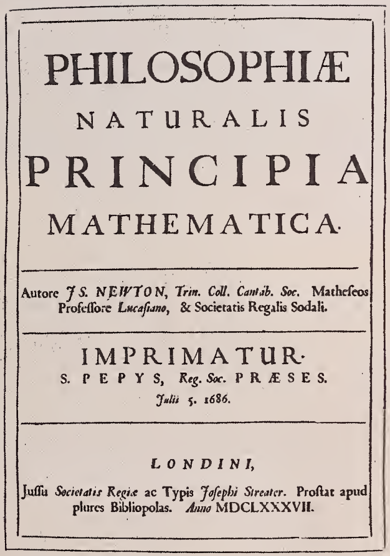
Copernicus and other astronomers thought that the circular motion of the heavenly bodies was a "natural motion," just as the falling down of any object not held up by something was a natural motion.

Newton questioned this idea. He formed his own idea: the only natural motion objects have is that they move uniformly along a straight line. This idea later became the basis of Newton's *First Law of Motion.*

Next Newton thought, if the planets orbit the sun and the moon orbits the earth in circular motions, then something must get in the way of their normal straight-line motion. There must be a force that causes them to go off their straight-line paths into the circular paths.

The moon, he thought, must be revolving around the earth because the earth attracts it. And at the same time things on the earth's surface fall toward the earth. He reasoned that the force that keeps the moon in its monthly orbit around the earth is the same force that makes apples fall earthward.

After much mathematical figuring, Newton decided that gravitational pull is strong or weak depending on the distance an object is from the earth. This idea laid the groundwork for his *Law of Universal Gravitation,* which says that massive objects pull each other harder than less massive ones. The pull is greater between objects near each other than between objects that are far apart. Newton believed that these two statements were also true for objects in space; that is why he used the word *universal,* meaning "everywhere in the universe."



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J. S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Jussu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Galileo and others could not find the answer to why the moon, under the earth's gravitational pull, does not fall into the earth as does an apple. Newton's answer was that it is falling every moment toward the earth.

The moon falls around the earth following the earth's curvature. It also pulls back on the earth. In fact, according to his universal law, every object, even a tiny meteor far out in space, must pull every other object. The apple that fell from the tree pulled the earth at the same time that the earth pulled the apple. But the apple's pull was so weak that it was not noticed. In the same way, the moon pulls the earth. And the earth pulls the moon. But because the moon is very far away, and also in motion, it cannot fall into the earth. The gravitational force between the earth and the moon is just enough to keep the moon in orbit about the earth.

Newton spent almost twenty years testing, proving, and improving his early theories before publishing his *Principia*, which contained his *Law of Gravitation* and the *Laws of Motion*. This book presented so much new scientific knowledge that some of the greatest triumphs of human thought can be traced back to it.

Isaac Newton contributed greatly to his own time and to future generations.

in this book. He studied optics and was the first to show that white light consists of light of different colors mixed together. He conceived the corpuscular theory of light, which reigned supreme as an explanation for the behavior of light until supplanted (in part) by the wave theory. He explained the elliptical orbits of the planets around the sun, the cause of the tides, and the irregularities of the motion of the moon. He invented the calculus, simultaneously with Leibniz, and invented and constructed the first reflecting telescope, the predecessor of the giant astronomical telescopes of today.

His greatest accomplishment, however, was to establish a method of discovery and investigation that has been followed since by all scientists. Newton was the first to use mathematics in formulating new theories, the first to form a theory from known facts and to deduce new facts from that theory that could be proved or disproved, and the first to use his theories to predict new phenomena.

Newton's life is of such interest that it cannot help but appeal to those of your pupils who are interested in mechanical devices and in experimentation.

TEACHING SUGGESTIONS
(p. 88)

LESSON: Are the orbits of the moon and the earth like those of the artificial satellites we have discussed?

Background: The material on this page takes the preceding discussion one stage further. Just as an artificial satellite falls toward a continuously receding earth, so does the moon; the earth and the other planets fall toward a continuously receding sun. The similarity of all these motions speaks for the universality of gravitational force in the universe, but this is a topic that will be developed in Unit 5, *Astronomy*.

Learnings to Be Developed: All orbiting bodies seem to follow the same laws of motion, implying that the force of gravity operates throughout the universe in exactly the same way.

Developing the Lesson: The continued development of the ideas introduced in the preceding pages is the main point to be emphasized. This lesson can be assigned for home reading before being discussed in class.

Some Other Orbits

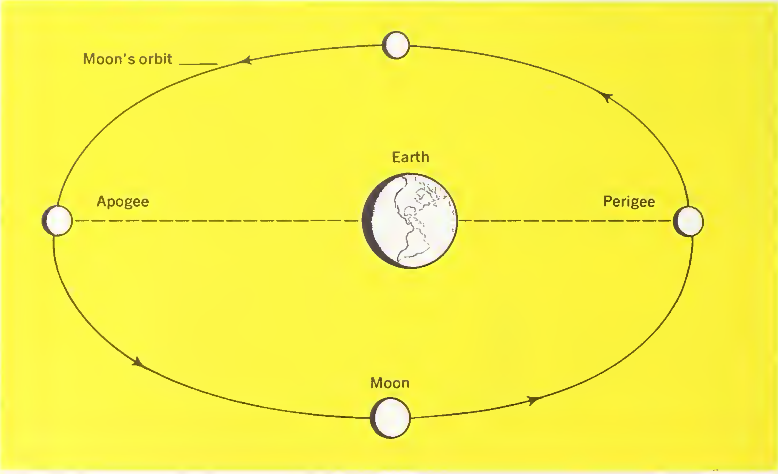
The Moon

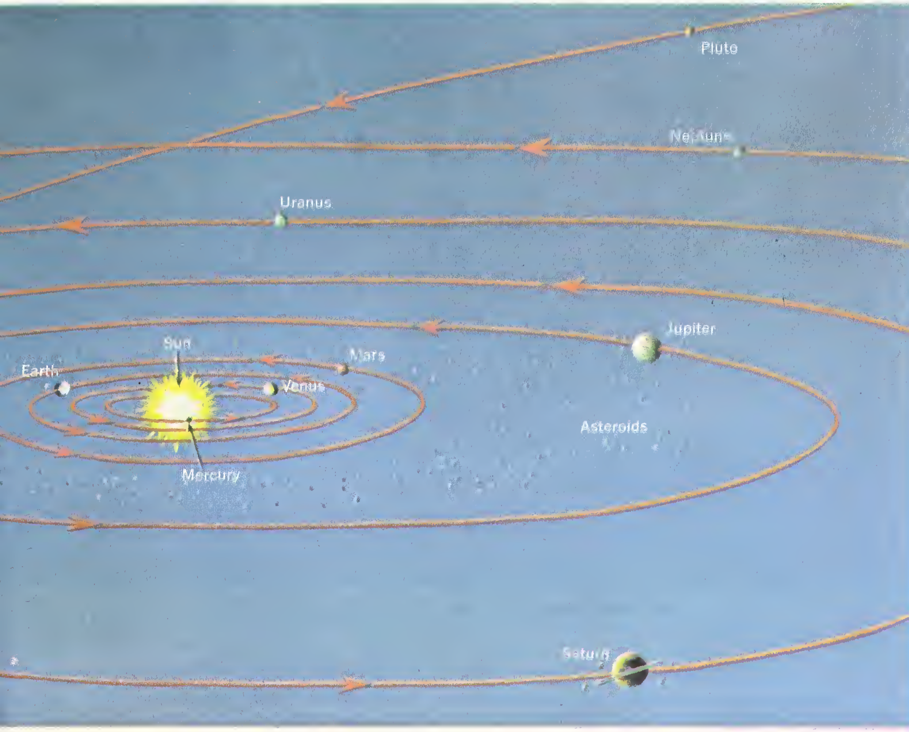
The moon orbits the earth in about 27 days at an average distance of about 240,000 miles. At perigee it is about 32,000 miles closer to the earth than it is at apogee. It travels at about 2,300 miles per hour in its elliptical orbit about the earth.

Like a launched eraser or a space capsule, the moon is always falling toward the earth. But its speed is great enough to keep it in orbit. Below you see a picture of the moon's orbit about the earth.

The Earth

The earth is in orbit around the sun, as are all the planets in our solar system. The sun is a much more massive body than the earth; therefore, there is a greater gravitational attraction between the sun and nearby objects than between the earth and objects that it attracts. For the earth to orbit the sun, it must travel at a higher speed than that of an object orbiting the earth. The earth moves at an average speed of about 18 miles per second in its solar orbit.





How does Pluto's orbit differ from the orbits of the earth and other planets? How does the gravitational attraction between the sun and the different planets vary?

Comets and Their Orbits

Also moving around the sun are objects called **comets** (KOM-its). Comets travel along very long ellipses. Actually, there are hundreds of thousands of comets, but they rarely come close enough to the sun to be seen from earth. Astronomers think that comets were far out in the solar system when the earth and the other planets were formed. They may be many miles in diameter.

Now and then a comet flashes in toward the sun. As it nears the sun, the outer layers of the comet melt off

TEACHING SUGGESTIONS
(pp. 89–90)

LESSON: Is gravitational force universal?

Background: The current theory concerning comets that is most widely accepted is that they are conglomerations of dust and ice particles floating in space—they can be compared to "dirty snowballs" about a mile or so in diameter. Normally they are invisible, but as they approach the sun, the sun's radiations ionize these particles and cause them to glow, which is why they are visible at such enormous distances despite their minute size. The tail of a comet consists of these ionized particles that are pushed away from the head of the comet by the pressure of the sun's radiation. The tail of a comet always points directly away from the sun.

This section concludes with a statement concerning the universality of gravitational force, a point to be emphasized.

Learnings to Be Developed:

Gravity operates throughout the universe.

The orbits of all the heavenly bodies can be explained exclusively in terms of gravity and of Newton's Laws of Motion.

Developing the Lesson: This section concludes the discussion of acceleration and of gravitation. Take this opportunity to sum up the concepts of this unit. The point of view that might be taken is that all moving objects, from the smallest to enormous bodies like the sun, the planets, and distant galaxies, obey the same laws. Everything moves according to the simple principles developed here.

It is likely that, during the astronomy discussion, one of your pupils will mention Halley's comet.

Edmund Halley was an English astronomer (1656–1742) who was long a friend of Newton (Pathfinder, page 86). He applied the new laws of gravitation to those "outlaws of the skies" and explained their apparently erratic behavior.

One of the comets he personally observed was that of 1682. On looking over records of previous comet sightings, he noticed a similarity to those of 1456, 1531, and 1607. He decided that all these sightings were of the same comet and predicted its return around 1758. It did reappear as predicted, and again in 1835 and 1910. Astronomers believe its next appearance will be in 1986.

This is a photograph of a comet seen on October 19, 1911.

and form a traveling cloud of tiny particles that we can see. This cloud is the comet's tail.

Comets have very little mass compared to the planets. Therefore, according to the laws of motion, they are easily accelerated. Sometimes a comet passes near the massive planet Jupiter. The strong gravitational attraction of this planet changes the comet's path, putting it into a different orbit.

When the astronomer studies the planets, the stars, and the bits of dust between them, he finds that everything is always in orbit. A tiny asteroid is in orbit around the sun. So are the planets. The sun orbits the center of our galaxy. Nearby galaxies orbit each other. All objects in space have a motion resulting from some force that started the object moving when it was created. Gravitational forces accelerate the objects in motion in curved, elliptical paths.

All objects in the universe seem to follow the same laws of motion.

Using What You Have Learned

1. Ask a friend to sit in a wagon and hold on to the sides. Start to pull the wagon suddenly. Notice what your friend must do to keep from falling out. Explain your friend's reaction by using the laws of motion.

2. At the earth's surface the acceleration of a freely falling object is 32 feet per second each second. That is, after one second, a freely falling object is traveling 32 feet per second. How fast is it traveling after two seconds? After three? After four?

3. When you round a sharp curve in an automobile, you must brace yourself, or you fall over. Why?

4. A ball is dropped from a very tall building. Do you think it keeps accelerating at 32 feet per second per second for the entire trip? Why?

5. A spacecraft on a trip to the moon requires fuel for launching, no fuel for the travel through space, but fuel again for the landing. Why is it necessary to use fuel for a safe, soft landing?

6. Find out about Galileo's experiments with freely falling objects.

7. Galileo investigated many fields of science. Find out about some of his important discoveries in astronomy.

8. Give practical examples of Newton's First and Second Laws of Motion.

9. Find out how Newton's Laws of Motion are applied to the design of rifles.

10. Explain why you reach a constant speed on a bicycle even though you continue to push on the pedals.

TEACHING SUGGESTIONS
(p. 91)

Background: The answers to *Using What You Have Learned* are:

1. The body will jerk backwards as the wagon is pulled forward. This is inertia—the tendency of a body at rest to remain at rest.

2. 64 feet per second; 96 feet per second; 128 feet per second.

3. Inertia again — moving bodies tend to continue moving in a straight line.

4. Yes. Gravity attracts it continuously during the entire trip. Only from a building as tall as the Empire State would friction begin to affect the rate of acceleration.

5. To overcome the acceleration toward the moon.

6. The experiments at the Leaning Tower of Pisa.

7. Invented the telescope and discovered the moons of Jupiter.

8. Centrifuge, laundry dryer, spinning top, automobile brakes, etc.

9. Sights are adjustable for various distances. The projectile cannot go in a straight line.

10. The constant force applied is counteracted by frictional forces, which tend to stop the bicycle.

TEACHING SUGGESTIONS
(pp. 92–93)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned:

This is a summary of the entire unit, with new words in boldface type.

Checklist of Science Words:

Remind the pupils that there is a *Dictionary of Science Words* on pages 390–393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

WHAT YOU KNOW ABOUT

Objects in Motion

What You Have Learned

All objects seem to follow the same laws of motion.

To start an object moving, the **balance of forces** must be upset. A moving object will continue to move unless a force acts to stop it. **Frictional forces,** caused by the rubbing of one object against another, may stop an object. Isaac Newton's **First Law of Motion** states that an object at rest will remain at rest, and an object in motion will continue to move in a straight line at constant speed, as long as no other force is exerted on the object. If enough force is added to a moving object, the object will accelerate. The acceleration of an object in a certain direction depends on the size of the force, the direction of the force, and the mass of the object. The mathematical relationship of force, mass, and acceleration as worked out by Newton is called the **Second Law of Motion.**

If an object is accelerated to a horizontal speed of 5 miles per second, it will go into orbit around the earth.

If an object reaches a horizontal speed of 7 miles per second, called **escape velocity,** it will escape from the earth's gravitational effect and go into an orbit around the sun.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

apogee	comets	escape velocity
balanced forces	ellipse	perigee

Matching Test

Write the numbers 1 to 7 on your paper. Next to each number write the letter of the word or words described.

1. Forces that are equal in size and come from opposite directions.
2. Forces caused by the rubbing of one object against another.
3. If no outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at a constant speed.
4. If you double the force exerted on a certain moving mass, the acceleration doubles.
5. Forces represented by arrows.
6. The point of an orbit closest to the earth.
7. The point of an orbit farthest from the earth.

A. First Law of Motion
B. apogee
C. vectors
D. perigee
E. Second Law of Motion
F. frictional forces
G. balanced forces

Can You Tell the Law of Motion?

Look at the pictures below. Which law of motion is illustrated in each?

Matching Test:

1. *G.* balanced forces.
2. *F.* frictional forces
3. *A.* First Law of Motion.
4. *E.* Second Law of Motion.
5. *C.* vectors.
6. *D.* perigee.
7. *B.* apogee.

Can You Tell the Law of Motion?

Each of these examples illustrates Newton's Third Law of Motion—for every action there is an equal and opposite reaction.

TEACHING SUGGESTIONS
(pp. 94–95)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

What Are the Words?

1. Ellipse
2. Vectors
3. Balanced forces
4. Escape velocity
5. First Law of Motion
6. Frictional forces
7. Apogee
8. Perigee
9. Time intervals

Balanced or Unbalanced Forces?

Any time an object is in motion, the forces acting on it must be unbalanced; if they were balanced, the object would remain motionless. The pictures illustrate Newton's First Law of Motion—objects will continue to remain at rest or in motion unless acted on by an outside force. In the illustrations, the outside forces are gravity, the resistance of the air, and friction.

YOU CAN LEARN MORE ABOUT

Objects in Motion

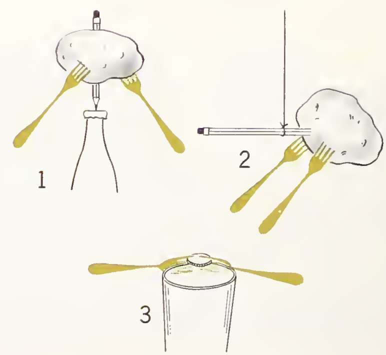
What Are the Words?

Write the words in your notebook.

1. The shape of most orbits.
2. These arrows tell how large a force is and in which direction it acts.
3. Forces that are equal in size and that are exerted in opposite directions.
4. The horizontal speed at which an object is traveling too rapidly to go into orbit around the earth: about 7 miles per second.
5. The statement that if no other force is exerted on an object, the object will remain at rest or continue to move in a straight line at constant speed.
6. Forces caused by the rubbing of one object against another.
7. The point on an elliptical orbit farthest from the earth.
8. The point on an elliptical orbit closest to the earth.
9. The equal periods marked off by the swings of a pendulum.

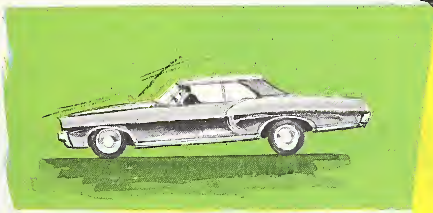
Try This

Use what you know about balanced forces to make the pictured setups.



Balanced or Unbalanced Forces?

Look at each picture and tell whether the forces are balanced or unbalanced. Which laws of motion are illustrated?



You Can Read

1. *Your World in Motion,* by George Barrow. Investigations of motion in air, water, and heat.
2. *Orbit,* by Hy Ruchlis. Tells about Newton's laws and shows how these principles are at work not only in ordinary activities but also in space flight.
3. *Things That Spin: From Tops to Atoms,* by Irving and Ruth Adler. A well-illustrated book that discusses various types of motion and compares them with the top.
4. *The Quest of Isaac Newton,* by Barbara and Myrick Land. Newton's discoveries and their importance to modern science.
5. *Isaac Newton,* by Patrick Moore. Newton's career and the relationship of his work to that of other men of his time.

Additional Readings:

What Makes the Wheels Go Round? by Edward G. Huey (Harcourt, 1953). Elementary physics: primary forces and some of their applications.

The 365 Days: The Story of Our Calendar, by Keith G. Irwin (Crowell, 1963). Motions of heavenly bodies, orbits of earth and moon; past calendars and why they failed. Good tie-in with Unit 1.

Isaac Newton: Mastermind of Modern Science, by David C. Knight (Watts, 1961). Biography and achievements against background of science before his time.

Johannes Kepler and Planetary Motion, by David C. Knight (Watts, 1962). Life and work of a founder of astrophysics, explaining development of his three planetary laws.

The Quest of Galileo, by Patricia Lauber (Garden City, 1959). His experiments in astronomy, gravity, and motion related to those of past and future.

Gravity, by Bertha Parker (Harper, 1956). Simple, well-defined explanation.

Faster and Faster: The Story of Speed, by Raymond F. Yates (Harper, 1956). Speeds attained by men, animals, and machines.

KEY CONCEPTS

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 3. To find order in the natural environment, the scientist seeks basic units that can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.

Key Concept 5. The motion of particles helps to explain such phenomena as heat, light, electricity, magnetism, and chemical change.

Key Concept 6. There is a basic tendency toward stability or equilibrium in the universe; thus, energy and matter may be transformed, but the sum total of matter and energy is conserved.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. Matter and electricity are inseparable.

4

Other concepts appear under "Learnings to Be Developed" in each lesson found in the Teaching Suggestions.

Electricity and Electronics

Electricity and Electrons

Electricity and Magnetism

2. Electricity may be produced in matter by friction, chemical action, magnetism, heat, and light.
3. Energy is the ability to move something by pushing or pulling it.
4. The atom is the smallest particle of matter that can be identified as an element.
5. Electric forces may attract or repel, whereas gravitational forces act in only one direction (attractive).
6. Protons and electrons are elementary particles and contain elementary charges.
7. An electric current is an electron flow—good in conductors, poor in insulators—determined by free electrons.
8. Electron flow produces a magnetic field.

PROCESSES:

- Observing—Pages 98, 99, 100, 101, 107, 126, 137.
- Experimenting—106.
- Comparing—98, 99, 100, 101, 106, 107, 137.
- Inferring—98, 99, 100, 101, 106, 107, 108, 113, 126, 137.
- Measuring—106, 126.
- Classifying—112, 118, 132.
- Selecting—102, 114, 137.
- Demonstrating—98, 99, 100, 101, 107, 124, 126, 137.
- Explaining—108, 109, 113, 131, 137.
- Hypothesizing—109.

TEACHING SUGGESTIONS
(pp. 98–101)

LESSON: What evidence is there that electricity is a property of all matter?

Learnings to Be Developed:

Matter and electricity are inseparable.

Matter gives evidence that it has electric properties.

Electricity may be produced in matter by friction, chemical action, magnetism, heat, and light.

Developing the Lesson: Pages 98 to 101 serve as an introduction to electricity. Much of what is covered might be considered review and reinforcement of previous experience. Some of the material on these pages will serve as background to later science study in this and other units. Have the pupils do activities suggested in the text to reinforce the ideas to which they have previously been exposed. The purpose of this unit is to unify these ideas into a more meaningful pattern and add additional information while broadening the concept of electricity and introducing electronics.

Additional activities and investigations are presented here that you can use either as alternate means of demonstration or for additional studies to produce discussion.

Electrons are responsible for the pictures on your television screen, the music that comes from your radio, and the flash of lightning in a thunderstorm. Understanding why electrons act the way they do and how they can be put to use is a new branch of science called electronics.

Electricity and Electrons

You flip a wall switch and your room is flooded with light. You push a button and a ringing bell instantly tells of your presence at the door. You turn a knob and a picture appears on the television screen. These are all effects of electricity at work.

What causes these effects? What is electricity? What is its source? Why do some materials allow it to move freely, and why do others not? How does electricity produce heat, light, and sound?

Finding the answers to these "whats" and "whys" and "hows" has been the work of many scientists for centuries. The forming of hypotheses, the making of models, and the performing of experiments to find out more about electricity continue today.

This unit will introduce you to the many wonders of the electrical world. You will learn much that scientists have learned about electricity.

Electricity and Matter

You know that all the things in this world are composed of matter. Gases, such as the air we breathe, are matter. Liquids, such as the water we drink, are matter. Solids, such as the bricks with which we build, are matter. Matter is just another name for substance, of which all things that exist are made.

Wherever matter exists in any form, electricity also exists. Matter and electricity cannot be separated. How have scientists shown that electricity is always joined with matter? Or, better still, how can you show this?

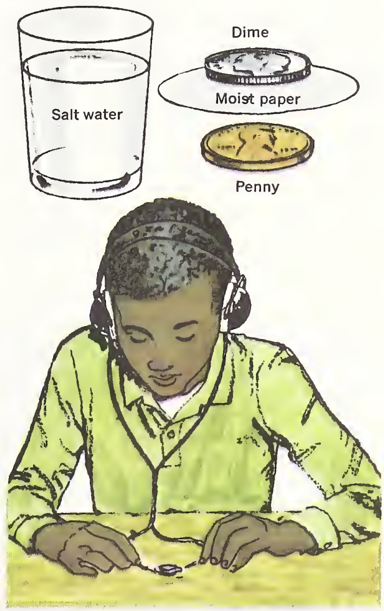
On a day when the humidity is low, drag your feet across a thick carpet. Then slowly place your finger very near a metal doorknob or radiator. The tiny spark you see or the slight tingle you feel is an effect of electricity. You have shown that electricity is present in matter by rubbing matter against matter—your shoes against the carpet.

Can you think of other ways to show electricity in matter by producing *friction?* What other ways can you think of? Try some of them.

You can show that electricity is present in matter by chemical action. Cut a piece of brown wrapping paper to the size of a nickel. Moisten the wrapping paper with water in which some salt has been dissolved. Sandwich the moist wrapping paper between a penny and a dime. Touch the dime with one tip and the penny with the other tip of the wires connected to a pair of headphones, as shown in the picture. The "click" you hear is an effect of electricity. What are some of the things in everyday use that show by *chemical action* the presence of electricity? How can you tell these things work chemically?

Can you tell what will happen when the boy touches the knob as in the picture?

Tell how the boy is producing an electrical effect by chemical means?



Static electricity is the electricity that is observable when a single charge builds up in a spot. It is observable when a slight shock, a spark, or motion of visible particles occurs. The term "static" represents a distinction that is made between electricity flowing through conductors and a stationary charge.

You may want to introduce this section by calling to mind the history of static electricity. The fact that amber and some other substances, when rubbed, have the power to attract light objects was recorded as far back as 600 B.C. by Thales. William Gilbert, in his book on magnetism, attempted to explain this activity and called substances that behave this way "electrics." *Elektron* is the Greek word for amber (a type of resin from trees). The term "electricity" was first used in 1650.

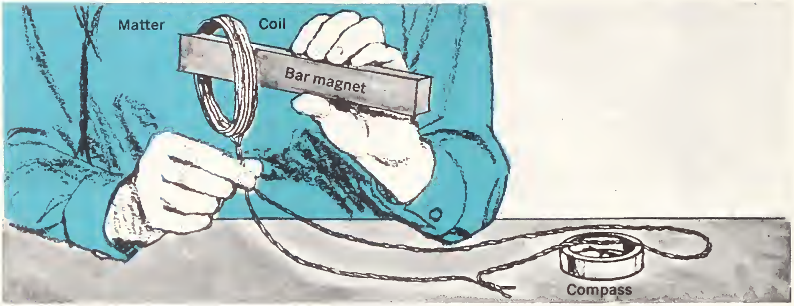
Have a pupil bring a woolen or nylon pullover sweater to class. The effects will be more noticeable if a long-haired girl is the pupil. After she has worn the sweater for a time, have her take it off. Sections of her hair will appear to rise and not fall into place at once. The child and possibly those near her should hear a crackling noise. If the room were dark, tiny sparks would appear. Suggest that they all try this at night.

Benjamin Franklin considered electricity to be a fluid (as did many others), which could be gained or lost by rubbing. He suggested that when a glass rod is rubbed with silk, the glass has an excess of this fluid. He called this excess a "positive" or "plus" charge. When he rubbed sealing wax with flannel it behaved a bit differently; he called the excess here "negative" or "minus." These terms remain today.

By vigorous rubbing of a plastic comb or fountain pen with a piece of woolen cloth, you should be able to generate a charge large enough to pick up bits of paper or cellophane.

Blow up a balloon and rub it vigorously in one direction on a woolen skirt. Now place the balloon against the chalkboard. It should remain there (opposite charges attract). With two balloons on a string, charge both; they will tend to push away from each other (like charges repel).

Chemical action shows that electricity is present in matter (p. 99). Have the pupils look up the work of Galvani (1737–1798) and Volta (1745–1827). Both were instrumental in beginning the study of chemical activity and electricity. See pp. 152–153 in *Science for Tomorrow's World,* Book 5.



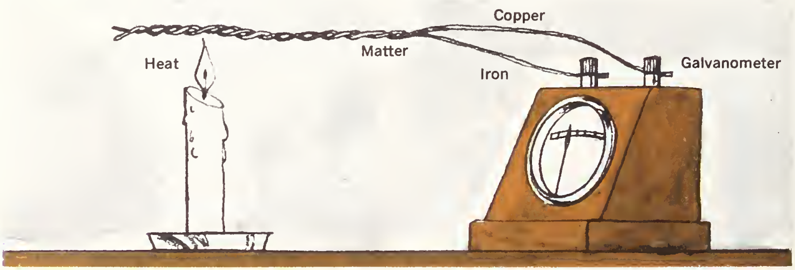
Tell how the boy is producing an electrical effect by means of magnetism.

Connect the bare ends of a coil of insulated wire to each other, as in the picture above. Place a length of the wire over a magnetic compass. Rapidly move a bar magnet in and out of the wire coil.

If an electrical effect is produced, it will be detected by the movement of the compass needle. Can you see the needle move as you do the activity?

Tightly twist together the ends of a piece of copper and a piece of iron wire. Connect the free ends to a **galvanometer** (gal-vuh-NOM-uh-ter). Heat the ends red hot with a candle. The heat causes electrical charges to move within the matter. That the electrical charges are moving is shown by the movement of the needle in the galvanometer.

Tell how an electrical effect is being produced by means of heat.



Science supply centers sell small, inexpensive photovoltaic cells that can power toy cars and trains. Perhaps some of the boys have them at home.

You can also show the presence of electricity in matter by using light. Connect a selenium photovoltaic cell or a silicon solar cell to a milliammeter. You can get these materials at radio and television or photographic supply stores.

Let a flashlight or other bright beam of light fall on the cell. Try blocking the light beam with your hand. Notice that the milliammeter reaches its highest reading only when the beam of light falls directly on the cell. Can you think of a photographer's device that makes use of this **photoelectric effect?**

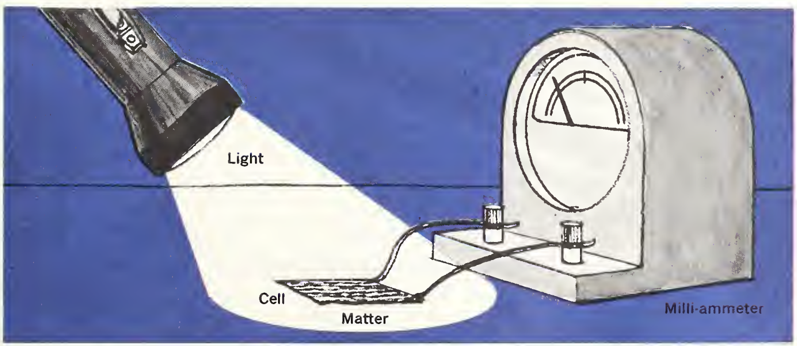
In each of the various tests you made—frictional, chemical, magnetic, thermal, photoelectric—matter was used in some form for the production of an electrical effect. Electricity is a property of all matter.

Energy

You know that electricity is present in matter. You have shown this by the five tests you performed. Since electricity is already present in matter, it cannot be generated.

However, *electrical energy* can be generated. *Energy* is the ability to move something by pushing or pulling. It is the ability to do work. Work certainly was performed by electricity in the five tests. How do you know this? Very simply, you saw meter needles move. You heard "clicks" produced in your headphones. And you saw and felt sparks or mild shocks. Because you acted on the electricity in matter in some way, you caused electrical energy to be generated to do this work. Can you think of other ways in which you can show that electrical energy is generated?

Tell how an electrical effect is being produced by means of light.



In addition to the salt-water-and-coin investigation on page 99, have pupils clean the two coins carefully, place them on their tongues, and touch the ends of the earphone leads to the coins. A click will show the presence of electricity. If the school has a galvanometer, and it should these days, repeat the activity above to show more clearly that current is being produced. A simple galvanometer is shown on page 100. Directions for making a galvanometer are given on page 124.

Magnetism shows that electricity is present in matter (p. 100). Have the students read and report on the work of Michael Faraday (1791–1867). See pp. 20–21 in *Science for Tomorrow's World,* Book 3. The pupils should concentrate on Faraday's producing an electric current by using a magnet, as in the top illustration.

More turns of wire of a smaller diameter should make the compass needle move more strongly.

Heat shows that electricity is present in matter (p. 100). If you have a sensitive galvanometer, perform this demonstration. Any two dissimilar wires should perform well.

Have the pupils look up the terms "thermocouple" and "pyrometer" and report their findings to the class.

TEACHING SUGGESTIONS
(pp. 102–103)

● **LESSON:** What are the elementary particles in organized matter?

Learnings to Be Developed:

The atom is the smallest particle of matter that can be identified as an element.

Neutrons and protons make up the nucleus of the atom.

The space around the nucleus has charged electrons, which are very light in comparison with other elementary particles.

Developing the Lesson: The photograph shows the areas where atoms of tungsten are present as white dots. They are not "pictures" of atoms or of one big atom. They simply locate the areas of electron activity about the center or nucleus. Each small dot *represents* a single atom's sphere of activity, magnified 800,000 times. Since the velocity of electrons is almost that of light, a photograph in the usual sense is not possible. The orderly arrangement is typical of crystal structure.

Drawing the analogy to the sun's planetary system is a good start, but we must go further. The planets' movements about the sun are all in about the same plane. Electron orbits are not. In fact,

Matter

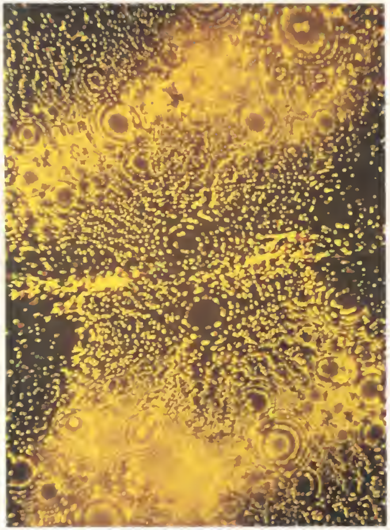
Why must matter always be present wherever electrical energy is generated? To find out we will study matter in more detail.

Matter can be divided into smaller and smaller amounts. For example, a large bar of metal can be cut into small pieces with a hacksaw. A file will reduce these small pieces to smaller pieces that are as fine as dust. A grinding mill will break the metal dust into such small particles that each becomes invisible unless viewed with a powerful magnifying glass.

Can this division of matter be continued to get smaller and smaller pieces, without limit? Scientists of the past thought not. They thought there was a smallest particle of matter that could not be divided further. They gave this smallest particle of matter the name *atomos,* which means "the indivisible." From this Greek word *atomos* we get our modern word **atom.**

Atoms

The scientists of the past were right in saying that there was a smallest particle that could not be divided, but they stopped too soon. The atom is the smallest particle of matter that can be identified as a chemical element. These atoms are called, for example, oxygen, sulphur, iron, gold, and uranium. Today, we know that atoms can be divided. They, too, are formed of smaller particles.



In this photograph you can see the atoms in tungsten crystal.

Hundreds of experiments have proven that an atom cannot be a solid. It is mostly empty space. At the center of the atom is a tiny particle forming a core. In the space around this core swiftly revolve other extremely small particles. These revolving small particles also rotate on their own axes. Can you describe the difference between revolving and rotating?

In the scientists' models, the atom resembles our solar system, but its scale is very, very small. There is a central sun with its revolving and rotating planets, and in between—nothing but empty space!

The Nucleus of the Atom

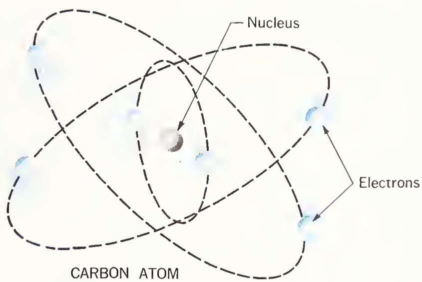
You will remember that the part forming the core of the atom is called the *nucleus*. *Nucleus* is the Latin word for "kernel." The nucleus is responsible for almost the entire mass of the atom, just as the sun is responsible for almost the entire mass of the solar system. However, the nuclei of different elements differ in mass.

Electrons

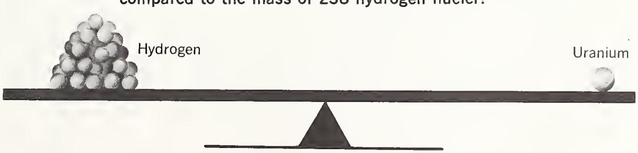
The word **electron** was derived from the Greek word for "amber." Amber was associated with electricity in ancient times.

The particles revolving around the nucleus and rotating on their own axes are the electrons. All the electrons in all the atoms of matter in the universe are identical.

Here is a picture of a carbon atom. How many electrons does the carbon atom have?



What can you tell about the mass of the uranium nucleus compared to the mass of 238 hydrogen nuclei?



The mass of 238 hydrogen nuclei would equal the mass of one uranium nucleus.

their orbits are constantly shifting. The electron spins on its axis and also orbits at a velocity close to the speed of light. With many electrons behaving this way, the atom can be described as a kernel of matter surrounded by a cloud of high-speed electrons. The mental image is thus less static than one given by a solar planetary system.

Since man has never "seen" an atom and never will, ask:

- *How can we detect the unseen?* (We do so by developing mental constructs and hypothetical models, which are changed, rejected, rebuilt, and refined to account for evidence that does not fit the older model. This is science as an intellectual pursuit.)

Man's ingenuity has developed instruments to extend his senses. Ask the class to give examples of some.

○ADDITIONAL ACTIVITIES:

To demonstrate how one constructs a theory: Before class begins, cut the roots from an expendable potted plant and carefully replace the top of the plant in the pot. As class begins, it should be well on its way to shagginess. Point to the plant and ask why it is dying or dead. Discuss theory formation. Finally, let pupils investigate directly.

TEACHING SUGGESTIONS
(pp. 104–105)

Background: Joseph John Thomson was born at Cheetham, England, near Manchester, on December 18, 1856, and died at Cambridge, England, on August 30, 1940. He was buried in Westminster Abbey.

Thomson was a precocious youth. He entered a college in Manchester when he was only 14. He won a scholarship to Trinity College, Cambridge, when he was 19, graduated second in his class in mathematics, and was appointed professor of physics there when he was 27. He remained at Cambridge all his life. Not only did he, himself, win a Nobel Prize for his investigations of the atom; seven of his research assistants also won Nobel Prizes for their work in atomic physics.

Prior to Thomson's work, atoms had been considered the smallest particles of matter.

Thomson discovered an even smaller particle, the electron, which was itself a constituent of every atom. Thomson's work was done with a Crookes tube, the invention of Sir William Crookes (1832–1919), another English physicist.

Crookes tubes of various designs, with which the effects described in

Joseph John Thomson

(1856–1940) England

The activity that occurs within atoms is fascinating. Perhaps even more fascinating is the story of how scientists developed a model of the atom without touching, seeing, or weighing it.

The tool that first enabled scientists to unfold the secrets of the atom was the Crookes tube. This tube, which came in many different shapes, was developed by Sir William Crookes. It was made of glass. At each end of the tube were two metal plates. The tube had a thin neck, connected to a vacuum pump, so that air could be pumped out of it. Both plates were connected to an electrical circuit. One plate was negative (the cathode), and the other plate was positive (the anode). As air was pumped out of the tube, glows of different colors and shapes filled the tube. Since the glows seemed to come from the cathode plate, they were called *cathode rays.*

Joseph Thomson was very much interested in cathode rays. He decided to do a series of five experiments with the Crookes tube.

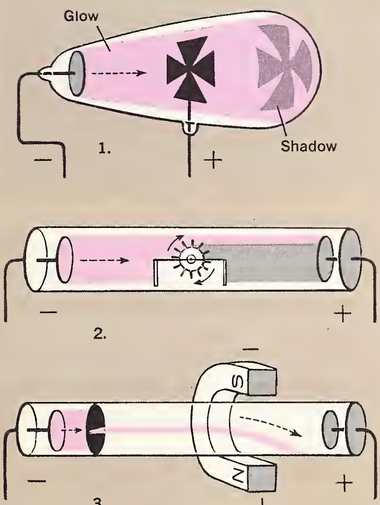
First Thomson coated the anode plate with a fluorescent chemical that he knew would glow when struck by cathode rays. Then he put a metal cross in the rays' path. A shadow of the cross appeared on the anode. This showed that cathode rays travel in straight lines.

In his second experiment, he put a paddle wheel in the path of the cathode rays. The rays started the wheel turning. He now knew the cathode rays were made up of moving particles of matter.

Third, he placed the north and south poles of a magnet on either side of the tube. He saw that the particles that made up the cathode ray were bent by the magnet. They bent in the direction of the positive plate, which showed that they had a negative electrical charge.

In his fourth experiment, he put electrically charged plates on either side of the stream of particles. By measuring the amount of charge necessary to bend the stream, Thomson was able to figure the weight of the particles. He found they were very, very light.

In the fifth experiment, he used different cathodes and put traces of different gases in the tube. The particles behaved in the same way each time. Thomson



then hypothesized that these particles were part of all matter and were always the same.

For nearly 100 years, scientists thought that the atom was the smallest unit of matter, that there was nothing inside the atom, and that it could not be divided. In 1887, Thomson reported his findings. He said that cathode rays are particles of negative electricity that come from within the atom. He also stated that atoms can be divided by the action of electrical forces. The particles from all kinds of atoms weigh the same and carry the same charge of negative electricity.

Thomson had discovered particles that could be found within every atom. He called these particles *electrons.* He suggested a model of the atom based on his observations. It was called the raisin-bun model. The atom was a solid ball (the bun) with a positive electrical charge. Within the ball were negative electrons (the raisins) scattered to form rings.

Other scientists followed Thomson, and their findings changed the model of the atom. But Thomson remains one of the first to unfold the secrets of the atom.

the text can be obtained, are available from all scientific supply houses.

Crookes in many ways anticipated Thomson's discoveries. He was certain, for example, that he was dealing with a new kind of matter and not with electromagnetic waves, but it was left to Thomson to prove that this was indeed true.

In addition to his work on electrons, Thomson made another major discovery. He was using a version of the Crookes tube to study the properties of neon atoms, which were discharged from the tube and struck a photographic plate, where their tracks were recorded. Thomson discovered that when a magnetic and an electric field were applied on the Crookes tube, three separate traces were recorded on the photographic plate. The traces turned out to be isotopes, or varieties of neon atoms with slightly different atomic weights. It was this experiment, much refined that led to the discovery of over 1,000 different isotopes of other atoms and the development of the instrument used to find them, the mass spectroscope.

A book that the pupils may find interesting is *Men and Discoveries in Electricity,* by Bryan Morgan (Transatlantic), which includes an account of Thomson's work.

TEACHING SUGGESTIONS
(pp. 106–107)

● **LESSON:** What is the source of electric force?

Background: On *force,* see Unit 3. A force is anything that produces, prevents, or changes motion or has a tendency to do so.

Learnings to Be Developed:

Electricity can produce forces.

Mass can produce a force.

Moving bodies, including the electron, exhibit inertia.

Developing the Lesson: Read the first paragraph aloud. Then analyze the first two sentences.

• *Did we ever use the word "inertia" before? What did it mean then?*

• *Is a picture on a wall exhibiting inertia?*

If you consider just the room, it exhibits inertia of rest. If the entire earth is the frame of reference, it exhibits inertia of motion.

• *Is the inertia of an electron the same as the inertia of a picture?* (For our purposes, yes. They both have mass. They are both matter. From the stars to the electron, all matter has inertia and mass.)

Electric Force

In the solar system planets tend to move out, or away from the sun, in a straight line. This tendency is called **inertia** (in-ER-shuh). *Gravitational forces* tend to pull the planets *inward,* or toward the sun. Because these forces are balanced, the planets remain in orbits around the sun, keeping the solar system intact.

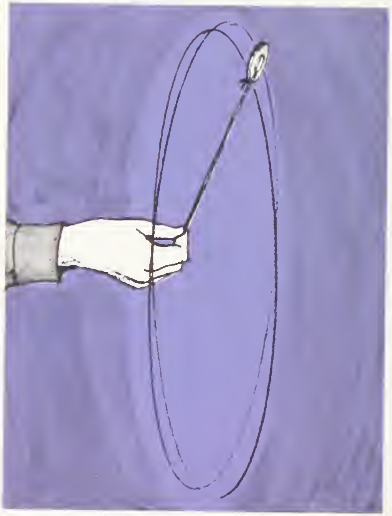
Electrons in the atom also have inertia. They tend to move out, or away from the nucleus, in a straight line. Because the speed of electrons is much greater than the speed of the planets, the gravitational pull of the nucleus does not affect the electrons as much as the gravitational pull of the sun affects the planets.

The tendency of electrons to move away from the nucleus is very strong. Size for size, inertia is much stronger for the electrons than it is for the planets.

Try this. Tie a large iron washer to a broken rubber band. Whirl the iron washer in a circle. As you increase the speed of the revolving washer, it exerts more force on the rubber band. What happens to tell you this?

Gravity is too weak a force to hold the swiftly revolving electrons in orbit. With gravity alone, the atom would fly apart. The force that holds the atom together is many, many times more powerful than gravity. It is electric force.

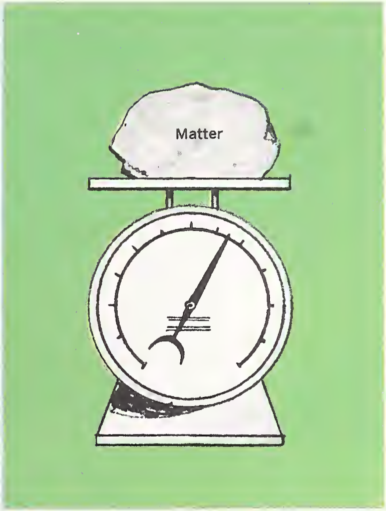
All matter possesses two properties. To one of these properties we give the name **gravitational mass.** Gravitational mass is the cause of gravitational



force. To the other property that all matter possesses we give the name *electricity.* Electricity is the cause of electric force.

The extremely small particles of the atom are responsible for electric force. All the visible effects of electricity—the

to $7\frac{1}{2}$ units of a standard mass when both are measured at the earth's surface. In space, far from the gravitational pull of large bodies, this rock would have the same



Matter possesses gravitational mass, which exerts gravitational force. How is this idea shown in the picture above?

driving of huge electric trains, brilliant strokes of lightning, the powerful illumination of gigantic searchlights—are the results of forces produced by these tiny particles.

Scientists do not yet know the basic material composing the particles of atoms. But they do know much about the behavior and effects of these particles. For this reason we can describe, at present, only the behavior and effects of electricity. This is all we know about gravity, too.

Attraction and Repulsion

We can compare electric force to gravitational force because each has the ability to move objects. But there are differences in how these forces behave.

For example, in the solar system, the gravitational force of the sun attracts the planets. The gravitational forces of the planets attract the sun and each other. There is only one kind of gravitational force, the force of *attraction*.

In the atom, the nucleus electrically attracts the electrons. The electrons, in turn, electrically attract the nucleus. But the electrons, instead of attracting one another, *repel* one another. There are, then, *two* kinds of electric forces. One kind is a force of *attraction*. The other kind is a force of *repulsion*.

You can demonstrate the difference between gravitational force and electric force for yourself. Get a sheet of colored paper. Place the paper on a table top. Obtain a thin piece of aluminum foil, a pair of scissors, and a plastic or hard rubber comb.

Hold the aluminum foil over the colored paper. Using the scissors, cut the foil into very small squares. Let them fall on the colored paper. Why do the squares fall downward? Are any of the foil squares repelled upward? What does this tell you about the force of gravity exerted by the gravitational mass of the earth?

mass but would have a weight of zero (weightlessness). Weight is a measure of the earth's pull on a body.

TEACHING SUGGESTIONS
(pp. 107–110)

● **LESSON:** How does observing the forces of attraction and repulsion enable us to describe two types of charges?

Learnings to Be Developed:

Electrical forces attract.

Electrical forces repel.

Like kinds of electricity exert a repelling force on each other.

Unlike kinds of electricity exert an attracting force on each other.

Developing the Lesson: By performing the suggested activities and answering the questions in the text, you should lead the class to appreciate that thus far we are simply forming hypotheses from observed happenings.

The pupils know about electrons only because they have read about them. The Pathfinder on page 104 demonstrated their existence and mass.

In discussing the formation of the italicized principles (hypotheses) point out that these are assumptions we made.

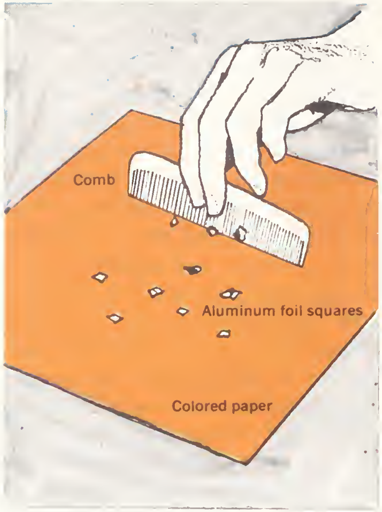
The activities in the text demonstrate the gravitational force of the earth on the aluminum (p. 107) and the electric forces of repulsion and attraction with a comb and the aluminum (p. 108).

Perform a series of demonstrations with two balloons suspended by string about four inches from each other. Touch each of them with a comb that has been charged by being rubbed vigorously by a piece of wool or fur. The balloons should pull apart from each other. Restore the charges to *neutral* by having a child touch both for a short while. Now renew the charges on the comb and wool by rubbing them together. Touch one balloon with the comb. Touch the other balloon with the wool. The balloons should be attracted to each other.

Discuss the implications of the above demonstrations in regard to the learnings listed.

Note: Experimenting with static electricity is most successful in cool, dry weather. Some pieces of equipment such as glass rods and combs work best when heated slightly. If you wish to test this idea, make a year-long assignment by asking pupils to report on a 3 × 5 card each time they notice static electricity. Tell them to watch people with woolen or fur outer wraps as they leave car seats with plastic covers, touch door knobs, etc. The record should contain:

1. Brief description of occurrence.
2. Date.
3. Temperature indoors or outdoors.



Now vigorously stroke your hair several times with the comb. Rapidly bring the teeth of the comb near the small squares of foil on the colored paper. What happens to the squares? Does this action show that electric force can be stronger than gravitational force? Why? Are some of the foil squares violently repelled from the comb? What does this tell you about electric forces?

Has the stored electrical energy in the comb performed work? What was the work? What had to happen before the stored energy could do work?

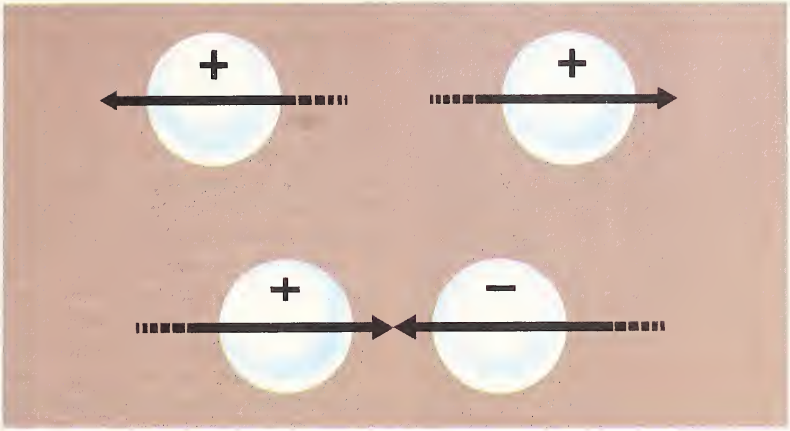
Kinds of Electricity

How are the two kinds of electric force, attraction and repulsion, explained?

Suppose we form hypotheses to provide the answer. We will assume that there are two kinds of electricity. We will then hypothesize that like kinds of electricity exert a repelling force on each other. This hypothesis will account for the observed electric force of repulsion. If we also hypothesize that unlike kinds of electricity exert an attractive force on each other, we can account for the force of attraction that we have observed.

These hypotheses seem reasonable. You can test them by referring to the facts you have learned. You know that all electrons are identical. Each electron carries the same kind of electricity. But all electrons repel each other. Therefore, *like kinds of electricity exert a repelling force on each other.*

Again, you know that an attractive electric force exists between the nucleus and the electrons. This is the attractive force that holds the atom together. But like kinds of electricity repel. Therefore, the electricity of the nucleus and of the electron must be of different kinds. Thus, we may state that *unlike kinds of electricity exert an attractive force on each other.*



What kinds of electric force are shown above? How can you tell each kind?

Have our hypotheses met the test of known facts? Could you form any other hypotheses about electricity and electric forces? Could you then test them by the known facts about the behavior and effects of electricity? Try to do so.

Two Kinds of Electric Charges

Since there are two kinds of electricity, they have different names. The kind of electricity of the electron is called *negative electricity,* simply to identify it and distinguish it from the other type. The electricity of the nucleus is therefore called *positive electricity.* You have already learned that the symbol for negative electricity is a negative, or minus, sign (—). The symbol for positive electricity is a positive, or plus, sign (+).

Neutrons and Protons

We have been discussing the nucleus of an atom as though it were a single particle. But long before atomic bombs or nuclear reactors were even imagined, scientists discovered that the nucleus is a cluster of small particles.

The small particles forming the nucleus are called **neutrons** and **protons.** Neutrons and protons are much heavier than electrons. In fact, each one weighs 1,840 times as much as

4. Humidity (dry or moist or not noticeable).

After some period of time attempt to analyze the records and see if conclusions confirm the statement concerning temperature and humidity.

In the diagram on page 109, the upper spheres are undergoing *repulsion,* if we are to take the arrows as direction vectors. Remind the pupils here of what vectors are. Arrows of equal length indicate equal magnitude of forces. The lower spheres are exhibiting *attraction.* The arrows show convergence, or motion toward each other.

When using the symbols + or −, or the words "positive," "negative," "plus," or "minus," take care that the pupils do not get the impression that these terms have any connection with mathematics. They are simply conventional symbols used out of habit since Franklin first presented them. The plus does not imply an excess of anything, nor does the minus imply a deficiency.

TEACHING SUGGESTIONS
(pp. 110–112)

LESSON: How do scientists design a model?

Learnings to Be Developed: Models are attempts to make sense out of unorganized data.

Developing the Lesson: Since the atom and its parts lie outside man's sense perceptions, the answers to what it consists of must rely heavily on trial-and-error guesses, observations of macroscopic matter under all conditions, more guesses (hypotheses), and then a plausible explanation.

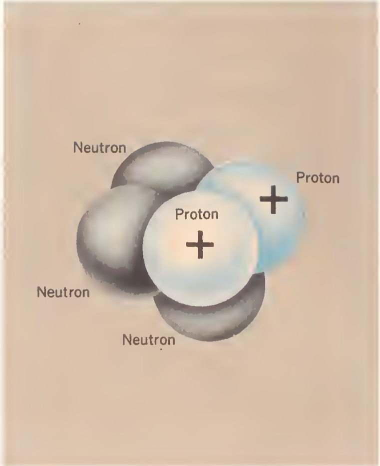
Here we shall attempt to explore what has been called the "black box."

You will need a shoe box, masking tape, and a few simple objects.

In order to devise something to challenge the children, you should first decide upon a suitable design. Place your design in the box, attached or loose. Place a cover over the box and seal it with masking tape. Your question is:

- *What is the nature of the contents of this box? You may examine the box in any way you wish without opening it.*

Teachers have used some of the following combinations successfully:



What can you tell about the nucleus of the atom above? How many electrons would the atom have?

an electron. This is why the nucleus is responsible for almost the entire mass of an atom. How does the total mass of an atom compare with the mass of a feather?

Neutrons are peculiar particles. Unlike protons and electrons, they possess gravitational mass, but they do not possess any electric charge. Because electric force is not exerted by the neutrons, these particles are of little interest to us in our present study of electricity.

Protons possess both gravitational mass and electric charge. Protons are the actual carriers of *positive electricity*. The nucleus has positive electric force because it contains protons.*

Atomic Structure

We learned earlier that an atom is made up of a nucleus around which electrons revolve. Now, we have looked inside the nucleus and found a cluster of neutrons and protons. Protons carry positive electricity, and electrons carry negative electricity. Neutrons are electrically neutral: that is, they exhibit neither positive nor negative electricity. There are still other particles in the atom that you will learn about in later grades.

Electric Charge

We shall now become familiar with a word we have used and will continue to use. The word is **charge.** It is used both as a noun and as a verb.

As a noun, *charge* means the quantity or amount of something—for example, money, gunpowder, or electricity. A service charge is the amount of money to be paid for the performance of work. A powder charge is the quantity of gunpowder placed in the barrel of a cannon. A charge of electricity is a quantity of electricity. You placed a charge of electricity on the comb when you stroked your hair in the aluminum-square experiment.

* Binding forces within the nucleus hold positively charged protons together.

As a verb, the word *charge* means to place a quantity or amount of something on or in something. You charge the cannon when you place gunpowder in the barrel. You charge a comb with electricity when you pass it through your hair. When a cannon is fired, it is discharged. When electricity is removed from a charged object, it is discharged.

Elementary Charges

It is believed today that electrons and protons are particles of matter that cannot be divided further. For this reason they are called **elementary particles.** It also is believed that the charges of electricity that these particles carry cannot be reduced. No smaller quantities of electricity have ever been observed. Scientists call these smallest quantities of electricity **elementary charges.**

The electron, of course, carries an elementary charge of negative electricity. The proton carries an elementary charge of positive electricity. Scientists have found that the elementary charge of negative electricity is exactly equal in quantity to that of the elementary charge of positive electricity. The positive charge of the proton and the negative charge of the electron produce the same amount of electric force. But how are the charges different?

The word *charge* can be used as a noun. For example, a gun crew places a charge in a gun. *Charge* can also be used as a verb. When a shell is placed in a gun, the gun is charged. Below, the gun is fired; it is *discharged.* Now apply the word *charge* to electricity, using it as a noun and as a verb.

Two dice (one glued to box) and a marble.

Piece of iron taped to a long tongue depressor.

A cheap watch taped to a golf ball.

Two wheels from a toy truck, one wheel having a glob of clay or putty on it.

After posing the question, move the box about, shake it gently, turn it upside down, attempt to balance it. Then ask:

- *Are there any guesses?*

Have children discuss the possibilities and feasibilities of their theories, constantly recalling previous evidence to support one theory or limit another.

When the class hypotheses are about exhausted, list the prevailing theories of what is in the box on the chalkboard and announce:

- *Now you will be allowed to investigate by yourselves. The box will be available for the next few days. Each day we shall spend a minute or two to list any new theories.*

Have magnets and scales available.

At the end of this exploration have a final analysis. Then open the box and discuss the theories in light of the exposure.

TEACHING SUGGESTIONS
(pp. 112–113)

● LESSON: What is a neutral atom?

Background: The drawings on pages 110 and 112 are purely diagrammatic. The particles in the nucleus, as well as the electrons around it, are in constant motion. They spin, they vibrate, and they move about one another. Many other more complicated motions take place. You should keep before the pupil the idea that the atom is a *dynamic* thing in all its parts.

There are 93 natural elements (atoms). Eleven man-made elements of short life span have been created in the laboratories of research centers.

Atoms are distinguished from each other by their chemical properties, which are in turn dependent mainly on the number and arrangement of electrons.

The nucleus of an atom contains the same characteristic number of protons and electrons in a balanced state. The *number of protons* is called the *atomic number.* All atoms, except the hydrogen atom, contain electrically neutral particles of about the same mass as a proton. These are called *neutrons.*

The only difference between the positive and negative charges is that like charges of electricity repel and unlike charges attract each other.

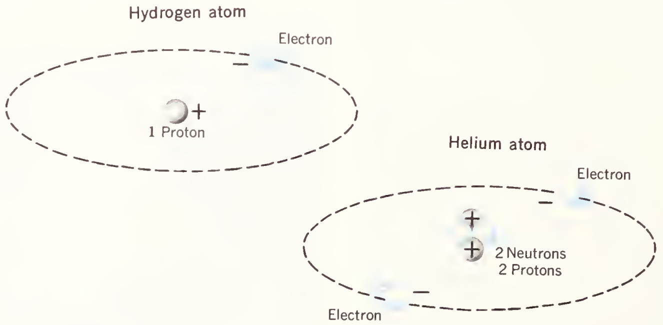
The Neutral Atom

Scientists have known for a very long time that the atoms of each element are quite different from the atoms of all other elements. For example, the nucleus of the lightest element, hydrogen, contains only 1 proton. The nucleus of the helium atom, the next lightest element, contains 2 protons and 2 neutrons. Uranium, the heaviest natural element, contains 92 protons and 146 neutrons. The number of particles in the nuclei of the atoms is fixed by nature.

Certain man-made elements, such as einsteinium, have nuclei that contain even more protons and neutrons than those of natural elements. As far as is now known, these elements do not occur naturally on earth; but they can be manufactured in machines called **accelerators** (ak-SEL-er-ay-terz).

Each atom usually contains the same number of electrons and protons. For example, the helium atom contains 2 electrons and 2 protons. Therefore, atoms usually contain the *same quantity of positive and negative electricity* and are therefore **neutral.**

How many electrons does the neutral uranium atom contain? How many positive and how many negative elementary charges does it then hold?



Use styrofoam, tinker-toy sets, or any similar materials to construct static models of some common atoms. Place + and − symbols on the protons and electrons.

Equal Quantities of Electricity

The element carbon provides a good model for studying the effects of equal quantities of the two kinds of electrical charges in the atom. (Carbon is used in the ordinary flashlight battery.)

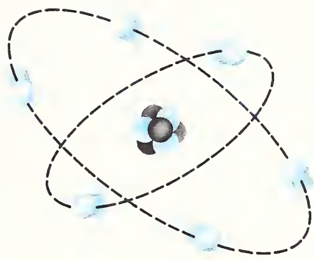
The carbon atom contains 6 protons within its nucleus and 6 electrons revolving about the nucleus. The atom thus holds 6 elementary positive charges and 6 elementary negative charges. The quantities of positive and negative electricity in the atom are equal to each other.

Imagine now that one electron, not attached to any atom, wanders near the carbon atom. The wandering electron should be attracted by the nucleus of the carbon atom. Why? At the same time the wandering electron should be repelled by the electrons of the carbon atom. Why?

The elementary charges of both negative and positive electricity exert equal forces. What effect does the carbon atom have on the wandering electron?

Since the electric forces of attraction and repulsion of the carbon atom are of the same strength, they cancel each other. Therefore, the carbon atom has no effect on the wandering electron.

Another way of thinking about this situation is to consider the charges themselves. The carbon atom contains 6 negative elementary charges, which together have a total value of —6 (minus six). The atom also holds 6 positive elementary charges, which together have a total value of +6 (plus six). If we add the two total charges, —6 and +6, the sum is, of course, zero. *The neutral carbon atom appears to have no charge at all.*



CARBON ATOM

All neutral atoms are electrically balanced. The electric forces exerted by the protons in the nuclei are cancelled by the electric forces exerted by the electrons. Mathematically, the total positive (+) and negative (—) charges of neutral atoms add up to zero. Thus *matter normally produces no electrical effects.*

To help you explain the diagrams on pages 112 and 113, a few common atomic elements are given here:

	Protons	Electrons	Neutrons
Hydrogen	1	1	0
Helium	2	2	2
Carbon	6	6	6
Oxygen	8	8	8
Iron	26	26	30

Atoms of the same element with differing numbers of neutrons are said to be isotopes of that atom. (e.g., carbon with 8 neutrons is an isotope of carbon). If the number of protons changes, then it is a different element.

This lesson can well summarize the major parts of the atom, considered as an electrical system.

Learnings to Be Developed:

Protons carry positive electricity.

Electrons carry negative electricity.

Neutrons carry no charge.

A charge is an amount of electricity.

Elementary particles cannot be subdivided.

Elementary charges cannot be subdivided.

An atom containing the same number of protons and electrons is neutral.

TEACHING SUGGESTIONS
(p. 114)

● **LESSON:** When work is done on an object, is energy conserved?

Learnings to Be Developed: Under ordinary circumstances, we cannot create energy. All we can do is change one form of energy into another form of energy.

Developing the Lesson: With the help of the following demonstrations, show that energy is conserved whenever work is done on an object.

Secure an elongated box with transparent sides. Balance it over a round object such as a broom handle or a desk pen. Place marbles in one end of the box. This will cause that end to fall lower than the other end of the box. Now ask the class:

- *How can we get the rolling marbles to strike the other end of the box?* (We must apply muscular energy to lift the end of the box so that the marbles roll in the opposite direction.)

Discuss the fact that chemical energy in our bodies had to be converted into the mechanical energy of our muscles in order to lift the box. Energy must always be expended in order to do work.

Work and Electricity

You have seen that matter, made up of billions and billions of charged elementary particles, normally does not have the ability to do work electrically. Certainly your desk, your chair, and your eraser do not, by themselves, produce electrical effects. Matter gains electrical energy, which is the ability to do work electrically, only as a result of certain actions performed on it.

What are these actions? What actions did you perform on matter to produce electrical effects? You dragged your shoes across a carpet, and you stroked your hair with a comb. In other words, you did muscular work on matter. This work produced electrical energy. The electrical energy, in turn, did work in generating a spark or in attracting and repelling bits of foil.

A similar series of events takes place when you play with a ball and bat. The bat and the ball have no ability to do work. The bat cannot hit the ball. You must swing the bat to hit the ball. You must do muscular work on the ball and the bat. The ball and bat now store energy and so have the ability to do work. (You are able to do this muscular work on the bat and ball because you have muscular energy. You obtain this energy from the food you eat.) When the bat hits the ball, its energy is used in doing the work of hitting the ball.

Mechanical energy, instead of electrical energy, is made by the work your muscles performed.

Producing Electrical Energy

How could you do work on matter to make, or generate, electrical energy? One simple way would be to reach into the atoms and yank out electrons. To remove an electron from an atom requires *work*. The force of attraction between the nucleus and the electron must be overcome, just as the elastic band on the slingshot had to be stretched.

Removing electrons from atoms is not as farfetched as it sounds. You actually did this when you stroked your hair with the comb. Since your hair contains carbon, we can again use a carbon atom as a model to show what happens.

The carbon atom has 6 electrons. If an electron is removed from a carbon atom, only 5 electrons are left. The carbon atom is no longer in a neutral condition, because the electric forces of its protons and electrons are not equal to each other.

Let's use mathematics again to prove this. We have in the atom —5 elementary charges, because we have only 5 electrons remaining. We have +6 elementary charges, because there are 6 protons in the nucleus. The sum of —5 and +6 is +1. There is an excess quantity of 1 positive elementary charge, which is free to exert an electric force outside the atom.

Since the carbon atom has the ability to exert an electric force, it has electrical energy. Electrical energy has been generated through work on matter that caused the removal of an electron.

If the wandering electron we talked about earlier came near the positively charged carbon atom, it would be attracted. Why? Would your hair, after being stroked by the comb, attract wandering electrons from the air? Why?

You also can place an excess charge on an atom by forcing an extra electron on it. In fact, you forced the electrons removed from the atoms of your hair onto the atoms in the comb. The comb gained the ability to exert an electric force: it attracted the bits of aluminum foil. Electrical energy was generated in the matter of the comb.

Can you figure out the excess charge on a carbon atom when an extra electron is forced onto it? What is the *sign* of the excess charge? What would happen to a wandering electron that came near such a carbon atom?

Whenever electrical energy is produced, matter has been worked on by something. Lightning bolts are the result of electrical energy generated by the work of violent air currents on water or ice particles. Whole cities are lighted by electrical energy generated by turbogenerators driven by the

TEACHING SUGGESTIONS
(pp. 115–116)

LESSON: How does man obtain electricity for his needs?

Learnings to Be Developed:

Work is done on matter to produce an imbalance of charges.

The devices for producing electricity are many.

Developing the Lesson: Ask the question above and discuss the answers in terms of *work* being done to cause a controlled flow of electrons. Answers may include:

1. Generators operated by falling water at waterfalls or dams. Attempts have been made to utilize the rising and falling of tides where the extremes are great.

2. Generators run by the work of expanding water (steam).

3. Generators run by the work of internal combustion engines (gasoline and diesel). These are for fairly local and small outputs.

4. Batteries, which utilize the chemical energy stored in the atoms of the electrodes and electrolyte and the activities that occur when the circuit is closed. The dry cell on page 117 will be discussed in detail later.

5. Solar batteries, which convert radiant energy into electrical

energy. Various space capsules utilize this method and supply sufficient quantities to transmit signals over millions of miles to the earth.

6. Pyrometers utilize the energy of heat to unbalance electric charges and cause slight flows.

7. Nuclear forces have the ability to produce large supplies of useful electromagnetic energy, but as yet there have been no successful designs worthy of consideration for large-scale production.

ADDITIONAL ACTIVITIES:

Assign a group to investigate the power source for your school's electricity. Does the school have an auxiliary power source? Find out where the electricity used by the local telephone system is generated.

If possible, make a field trip to a local generating plant, either a public utility or a power station used by a large manufacturing complex.

How are the lightning bolts produced? How can houses be made safe from lightning? *

work of falling water. In the five tests at the beginning of this unit, work from friction, from chemical action, from heat, from moving magnetic fields, and from light acted on matter to generate electrical energy.

In each of these examples electrical energy was generated through only one process! Electrons were added to or subtracted from neutral atoms of matter. The atoms gained excess charges of negative electricity or became positive by loss of electrons. The excess electrical charges enabled the matter to exert an electrical force.

Electrical Energy Generators

The action that takes place within the dry cell flashlight is an example of electrical energy being generated.

A dry cell is made up of a zinc sheet formed into a cup shape. The cup is filled with a chemical paste. Suspended in the paste is a carbon rod. Binding posts are attached to the cup and rod. Connections can be made to these posts so that the electrical energy generated by the dry cell can be drawn off and used.

The chemicals in the paste react with the zinc of the cup to do *chemical*

*Lightning bolts are produced because of the difference in electric potential between clouds and the earth below. When the difference in potential becomes large enough, a lightning bolt is discharged, which reduces the potential. Lightning rods attached to houses will conduct the bolts harmlessly into the ground.

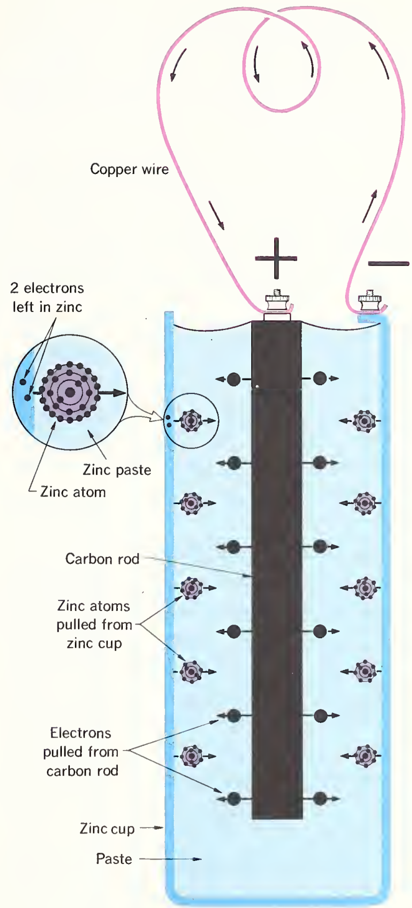
work. This chemical work consists of pulling billions of zinc atoms out of the cup. The zinc atom contains 30 electrons. How many protons does it contain?

As each zinc atom leaves the cup, 2 of its 30 electrons are left behind in the zinc sheet. As a result, the zinc sheet will contain more electrons than protons. The cup gains a *negative* electric charge. This negative charge can exert an electric force. The electric force can repel wandering electrons.

To show what happens, we connect a wire to the dry cell, as shown in the picture. (*A wire should never be left connected in this manner. It would ruin the dry cell.*) The wire provides a path along which electrons can travel. Electrons can move through this wire path much more easily than they can move through the air.

The billions of excess electrons in the zinc cup are *repelling* each other with an electric force. The copper wire provides an easy path through which some of them can get away from the cup and to the carbon rod.

The electrons move from the zinc cup, through the easy path of the wire, to the carbon rod. Work is being done in keeping these electrons moving. Electrical energy to do this work is generated by the chemical work being done inside the dry cell.



DRY CELL

Voltaic cells consist of two dissimilar conductors (electrodes) immersed in an acid, base, or salt solution (an electrolyte). In the cell on this page, electrons accumulate on the zinc and are conducted by the wire outside the cell to the carbon, which has a deficiency created inside the cell. The electron flow is from the zinc cup through the conductor to the carbon.

TEACHING SUGGESTIONS
(p. 117)

Background: If our model of electricity is correct, work must be performed to move electrons through the copper wire. The cell must possess chemical energy.

The typical "dry" cell is not dry. The dry cell is one form of *voltaic* cell. The sealed interior contains a moist paste consisting of two or three chemicals, usually ammonium chloride, powdered carbon, and manganese dioxide.

The ammonium chloride helps remove electrons from the carbon rod. The powdered carbon helps provide a partial conductor across the inside of the cell and reduces the work of moving electrons. The manganese dioxide prevents a build-up of hydrogen gas around the carbon rod by changing the hydrogen to water. The manganese dioxide oxidizes hydrogen.

Use a galvanometer to show the direction of electron flow. Connect wires from a small dry cell to a light bulb, then to a galvanometer, and then back to the cell. If you reverse the wires on zinc and carbon, the needle will show a deflection in the opposite direction.

TEACHING SUGGESTIONS
(pp. 118–120)

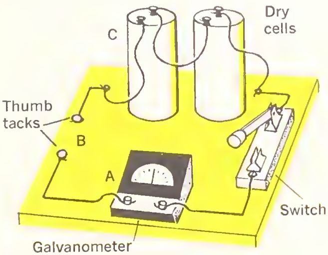
● LESSON: What materials conduct electricity best?

Learnings to Be Developed:

Materials through which electrons can flow easily are called *conductors*.

Materials through which electrons cannot flow easily are called *insulators*.

Developing the Lesson: Assign one of your more construction-minded pupils the job of making a simple electrical circuit like the one below. The circuit can be fastened by tacks and tape to a 12 x 12 ceiling tile.



At *A*, place a small detecting instrument such as a light bulb, a galvanometer, a D-C ammeter, or a toy motor. At *B*, have the bare wire wrapped around thumbtacks. These will be your contact points for testing materials. The

The action we have traced—the changing of chemical energy into electrical energy—will continue until there is no longer any chemical energy available in the dry cell. The dry cell will then "go dead."

The cell that you built from a dime, moist paper, and a penny at the beginning of this unit, on page 99, worked in the same way as the dry cell. The chemical work performed by the salt solution in contact with the metals of the coins generated electrical energy. The dime acquired a positive charge and the penny acquired a negative charge. Electrons, forced through the wiring of the headphones, carried the electrical energy that produced the "click" you heard.

Conductors and Insulators

The wire connecting the binding posts of the dry cell provided a path through which electrons could easily move. Electrons were *conducted* from the zinc cup to the carbon rod. Any material through which electrons can easily flow is called a **conductor.** Any material through which electrons cannot flow easily is called an **insulator.**

Most metals—iron, zinc, aluminum, copper, silver, gold, platinum—are good conductors of moving electrons. Materials such as dry silk and cotton, hard rubber, ceramics, glass, plastics, wax, and even air are poor conductors, or insulators.

Why will some materials allow electrons to flow easily from one place to another, whereas others will not? Once again we must look into the behavior of atoms to find out.

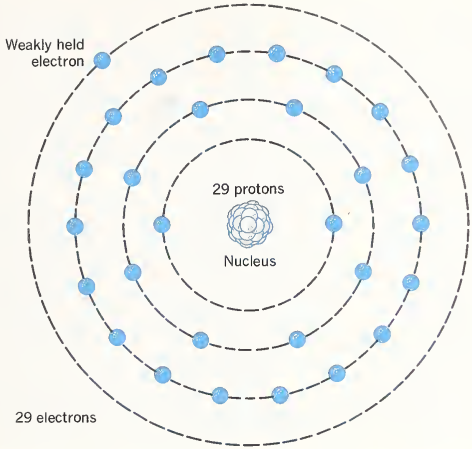
Weakly Held Electrons

Copper is an excellent conductor of moving electrons. Much of the electrical wire used today is made of this element.

The atoms of copper, like the atoms of all matter, are constantly moving to and fro. They are said to be

The atoms of all matter are in constant motion. Although the vibrations may be small, they are vigorous. How is this motion detected? *

*The Brownian motion of extremely small particles of matter, such as smoke particles or a suspension of talc in water, can be observed through a microscope. These motions are caused by molecules' striking the particles.



COPPER ATOM

vibrating. The to-and-fro motions are extremely small but very vigorous. Materials that seem solid to us are alive with this motion. We detect the motion as *heat.*

Things that seem very cold to our touch—that have low temperatures—still contain heat. Their particles are vibrating rapidly.

The neutral copper atom contains 29 protons and 29 electrons. The arrangement of the electrons in the copper atom produces a special effect. *One electron is held very weakly in the atom.*

A copper wire is made up of billions and billions of atoms. Some of the atoms lose their weakly held electrons because of the vigorous atom vibration. The weakly held electrons are shaken loose and escape from their parent atoms. They become free. These free electrons will then wander through the empty space that is between the atoms in the wire.

But these electrons do not remain free for very long, nor do they travel very far. Other copper atoms, which have lost their original electrons, will quickly recapture them.

dry cell is at C. Use more than one if you are powering a toy motor.

Place various coins, slugs, pieces of pencil lead (graphitic carbon), wood, plastic, moist paper and cloth strips, etc., between the two tacks and record the intensity, speed, or deflection of your indication device.

- *Which seem to be good and which poor conductors of electricity?*

Ask for criticisms of the procedure, some of which might be:

The materials should all be the same size and thickness to get reliable results.

The recording instrument could not detect small differences (light bulb and motor).

Follow-Up: Invite the class to submit a testing device that could yield more accurate information.

Invite designs on a device for testing the conductivity of liquids or of gases.

Note: The conducting ability of substances is dependent on their atomic structure and their molecular arrangement. Dry sodium chloride (table salt) is a nonconductor. In water it is one of the best. In solution its ions dissociate and perform as independent particles.

TEACHING SUGGESTIONS
(pp. 120–122)

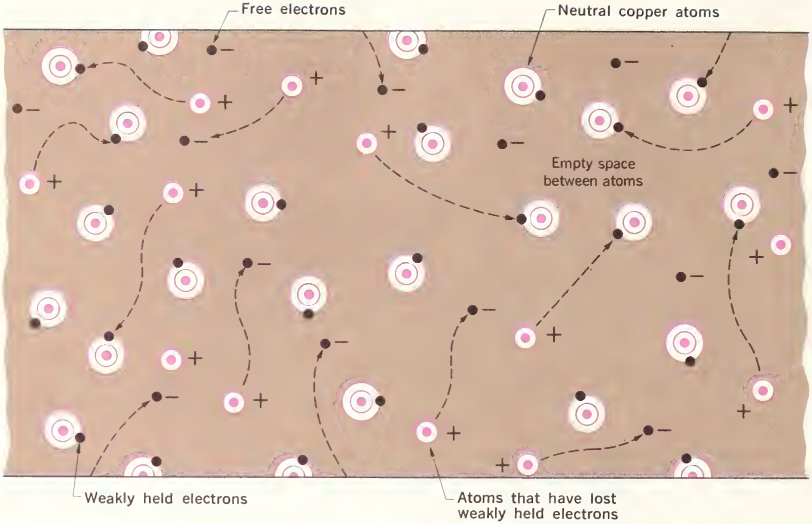
● **LESSON:** Do electrons flow in insulators and conductors?

Background: Matter can be classified into two main categories with regard to electrostatic properties: *conductors* and *semiconductors*. Conductors contain charges that are relatively free to move over large atomic distances in the material. In a semiconductor, most of which we call nonconductors, there are no such charges. In most nonconductors, the electric charge (that is, the movement of electrons through the material) can be displaced only over small atomic distances. With changes in temperature and in other properties, these so-called nonconductors can be made to conduct over larger distances.

In the final unit of this book we will discuss cryogenics as one method of inducing superconductivity (page 355).

Some common substances are listed below in order of electrical conductivity, with silver listed as the best conductor:

1. silver
2. copper
3. aluminum
4. tungsten
5. nickel
6. brass
7. iron
8. platinum



A SECTION OF COPPER WIRE

Notice that there are 13 atoms with a positive charge and 13 free electrons. The overall section of this wire is electrically neutral. How can you tell this?

When the weakly held electron escapes from the copper atom, only 28 electrons will be left. Since there are still 29 protons, the copper atom has a positive charge. It will attract free electrons. A free electron probably will be captured quickly by the charged atom, which will then again become a neutral atom and show no charge.

At any time, there will be many free electrons in the wire. It is because of these free electrons that copper and other metals are conductors.

Electron Flow in Conductors

What happens to free electrons when a dry cell is connected to the ends of the wire? We know that the negative post of the dry cell will push electrons into the wire, and electrons are pulled out at the positive post.

The free electrons are repelled by the negative electric force of the incoming electrons. Also, the free electrons are attracted by the positive electric force at the positive post of the dry cell. Under the influence of these forces, the

free electrons, during the time they are free, drift in the same direction, *away* from the *negative* post and *toward* the *positive* post of the dry cell.

As free electrons leave one end of the wire, space is made for electrons to move into the other end. The electrons from the dry cell, once inside the wire, are like free electrons. They hop from atom to atom, since they, too, are repelled by the electrons still coming in from the dry cell.

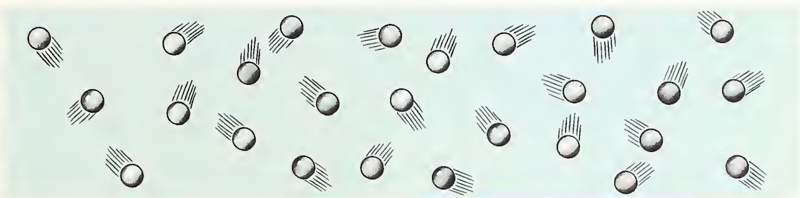
The effect is a continuous current of electrons flowing in *one* direction. Electrons in motion in one direction through a conductor are collectively called an *electric current*. Materials through which electric currents can freely flow are called good conductors.

Electron Flow in Insulators *

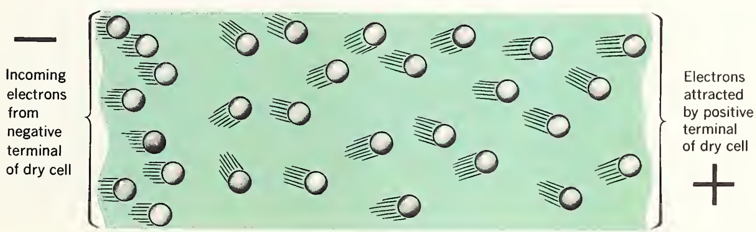
The behavior of electrons in insulators is very different from their behavior in conductors. Electrons do not become free and wander through the empty space between atoms. The atoms of matter making up insulators hold on to all their electrons. Violent vibrations will not shake electrons loose.

Since there would be no free electrons to move, there would be no current flow in a perfect insulator.

How would you describe the movement of free electrons?



In what direction do free electrons drift when under the influence of electric forces?



*Introduce the idea that insulators absorb only a very limited number of free electrons. Most of their electrons are bound securely to the individual atoms.

Learnings to Be Developed:

An electric current is an electron flow.

Flow is good in conductors.

Flow is poor in insulators.

The number of free electrons in a substance determines its ability to conduct electricity.

Developing the Lesson: Spend sufficient time exploring the diagrams (models) on pages 120 and 121. Emphasize the random motion of free electrons in the copper wire and their ceaseless activity. Were all this motion or a greater part of it organized in one direction, a *current* would be noticed. Ask:

- *What would happen if all free electrons were to move in one direction?*

Hold up a copper wire about 6 inches in length.

- *Describe all the motion you think is going on among electrons in this wire.* (Motions similar to planetary motions, interplanetary jumps, random movements of free electrons.)
- *If you attached both ends to the terminal of the battery, what changes in motion would take place?* (The major change would be a single direction flow *away* from the incoming electrons from the battery. The same explanation is given for the lower picture on page 121.)

ADDITIONAL ACTIVITIES:

Have the pupils list the conductors and insulators in their homes and tell how they are used.

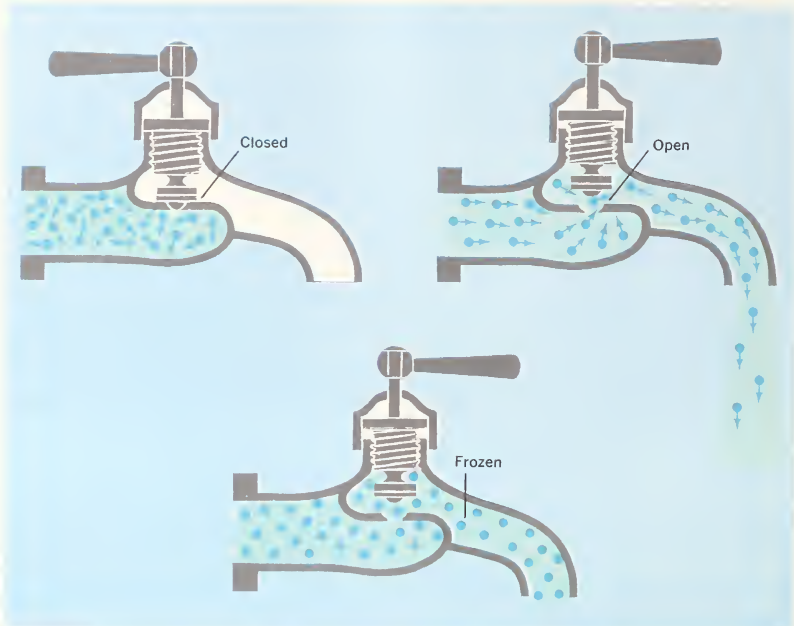
Have pupils look at the diagram of the dry cell on page 117 and list substances that are conductors of electricity and those that are insulators. (Conductors: zinc cup, carbon rod, brass caps on terminals, copper wires, paste in the cup. Insulators: covering of copper wire, bakelite seal at top of cup.)

Ask the pupils why insulators are necessary. (So that the current gets to where it is needed.)

With the class, inspect power lines around the school. They carry tremendous amounts of electricity. Ask:

- *How are insulators used?*
- *What designs do you notice on lines that are suspended from the light poles?*

Have the class report on why most good electrical conductors are made of the elemental metals, such as silver, copper, and aluminum, while insulators are usually made of complex compounds. First, have the class construct and discuss a theory on why this is so. Compare the informed answer with this theory.

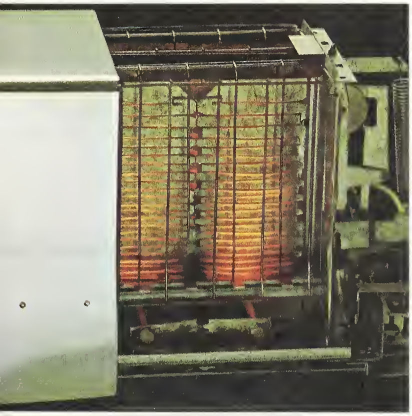


To understand better what happens in conductors and insulators, think of a pipe that is filled with water. The particles of water within the filled pipe may be compared to free electrons in a wire. These water particles are free to move under the influence of forces. If additional water particles are pushed into one end of the pipe, the whole column of water particles moves. Water particles immediately flow out of the other end of the pipe. A continuous flow of water particles through the pipe can be maintained. This action is like that in a conductor.

Now imagine that the water in the pipe freezes. The particles can no longer move freely. Additional particles of water cannot be forced into the pipe, nor can particles of water be withdrawn. This is something like what happens in an insulator.

Have the class read about the search made by Edison to find a conductor for this electric bulb.

Billions of electrons are flowing through the filaments of the light bulb and the toaster. What do you see happen when they flow through? *



Heat and Electricity

The free electrons moved through conductors by electric forces do not really have open paths. Their trips, from the time they escape from a neutral atom to the time they are captured by a charged atom, are more like obstacle courses, or zig-zagging, winding paths.

Vibrating atoms keep bobbing up in the free electrons' paths, and collisions take place. These collisions between free electrons and atoms cause the atoms to vibrate more vigorously. Heat is produced. The vibration of particles of matter produces **thermal** (heat) **energy**.

As the number of electrons flowing through a conductor increases, the number of collisions increases. As the motion increases, the temperature of the material increases. The material may become "white hot" when a very large number of electrons flows. For example, about 5,000,000,000,000,000,000 electrons flow through the average electric light-bulb filament every second that it is turned on.

Electrical energy is transformed into heat energy by the action described. Light, which is another form of energy, is also generated in this action. But this is done through a more complicated process. You might be interested in finding out about this process.

**Overheating occurs on overloaded circuits. At this point you might introduce the values of fuses and adequate wiring, the hazards of "octopus" outlets, etc.*

TEACHING SUGGESTIONS
(p. 123)

● **LESSON:** Why does a flow of electrons through a conductor produce thermal energy?

Background: Recall here the concept from Unit 2, *Heat and Molecules:* Vibrations of matter produce heat.

Learnings to Be Developed:

Electron flow increases the heat of a conductor by increasing the motion of its molecules.

The greater the flow of electrons, the greater the amount of heat generated, assuming the conductor remains the same size.

Developing the Lesson: Begin the lesson by having your pupils rub the palms of their hands vigorously on the tops of their desks. Remind them of the experiments and demonstrations done when studying the effects of friction: Heat was produced by matter in vibration against other matter. Ask:

- *We have already studied the characteristics of electron flow. Why do you suppose such a flow creates heat?* (The first learning above answers this.)
- *Can you think of any conditions in your home that might show the effect of increased electron flow?*

TEACHING SUGGESTIONS
(pp. 124–125)

Background: One of the abilities necessary to a scientific investigation is the ability to design and, at times, to construct a piece of equipment that either does not yet exist or is unavailable. The learnings are derived from the construction of simple instruments, such as the galvanometer on this page and are worth the time and effort needed to master them.

Children at this age are not equally adept at construction. For this reason, you should encourage interested pupils to undertake the building of the galvanometer and even encourage innovations in the design of it. Such innovations could well constitute a project entry into a school or district science fair.

This is an outside project; it could take a couple of weeks to do.

Galvanometers of more precise construction can be purchased at science supply houses. A few suggestions are offered below:

A small galvanometer of good construction with a 4″ dial can be ordered from Welch Scientific Co., 7300 North Linder Ave., Skokie, Illinois, 60067. Cat. #2732–Cadet Galvanometer.

Using What You Have Learned

Make a laboratory galvanometer. Use it to test as many as possible of the following:

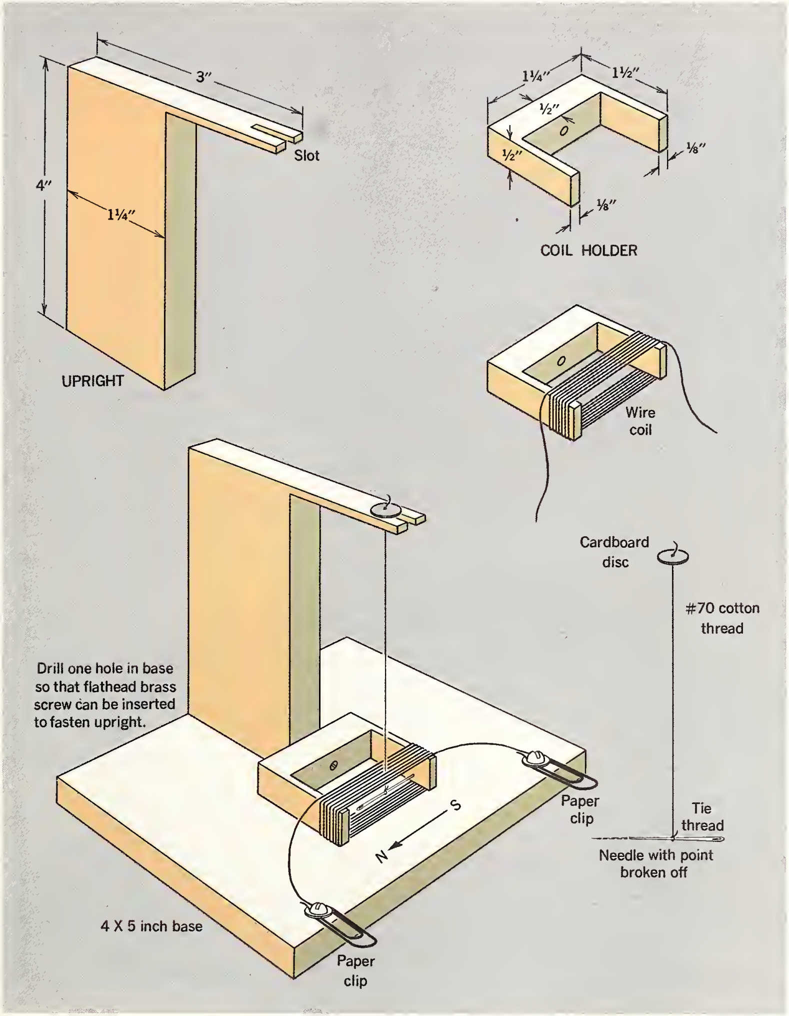
selenium photovoltaic cells
silicon solar cells
dime-penny cells
wire coil and bar magnet generators
other generators of electrical energy

To make the galvanometer, cut the upright, the coil holder, and the base from ordinary pine shelving to about the sizes shown. Drill holes in the base and the coil holder to take small *brass* screws. Fasten the upright to the base with one screw.

Wind the coil holder with 200 turns of #30 or #32 enameled wire. Do not pull the wire too tightly when winding, or the coil holder will be split. Leave the ends of the coil long enough to reach the paper-clip binding posts. Fasten the coil holder to the upright so that the coil clears the base by about one-quarter inch.

Mount the paper clips on the base with small brass roundhead screws and washers. Fasten the coil leads under the screwheads. Use fine sandpaper to remove the enamel from the wire ends so that electrical contact will be made.

Using pliers, break the point from a medium-sized sewing needle. Magnetize the needle by stroking it in one direction on one pole of a strong permanent magnet. Tie the needle to #70 cotton thread. Hang the thread from a cardboard disc. Adjust the thread so that the needle is balanced horizontally and hangs in the center of the coil. Turn the cardboard disc so that the needle is parallel with the coil. The coil should be positioned in a north-south direction, since the earth's magnetic field will influence the needle.



Stansi Scientific Co., 1231-41 North Honore St., Chicago, Illinois, 60622, has a similar instrument with an $8^1/_2''$ diameter. Cat. #4962–Demonstration Galvanometer.

Both Stansi and Welch offer other materials useful in this unit:

Magnet Model:	Welch #1800
	Stansi #3699
Lodestone:	Stansi #3600
Electroscope:	Welch #1963A
	Stansi #3899

An inexpensive electroscope kit is available from MacAlister Scientific Corp., 60 Arsenal St., Watertown, Mass., 02172. Cat. #MSC 901.

TEACHING SUGGESTIONS
(pp. 126–127)

LESSON: What effects are produced in the area around an electric current?

Background: Historically, the possibility of having a continuous flow of electricity led to the study of various interactions between electric currents and magnets. Most of the basic laws describing these interactions were uncovered early in the last century. In 1820, a Danish scientist, H. C. Oersted, noticed the same effects described in the experiments on these two pages (a compass needle is deflected by the current). Two French physical scientists, J. B. Biot and F. Savant, refined these findings and noticed that the forces (magnetic) that orient the needle increase with the strength of the current and with the proximity of the needle. This was the basis for the design of the galvanometer.

Learnings to Be Developed:

Electron flow produces a magnetic field.

A magnetic field surrounds a conductor in which there is an electric current.

Developing the Lesson: Have a cut-out cardboard resembling the illustration on page 127 prepared before class by a pupil. A shirt

Electricity and Magnetism

In the third of the five tests you did at the beginning of the unit, you placed a wire over a magnetic compass. When an electric current (a flow of electrons) passed through the wire, an effect was seen: the needle of the magnetic compass moved. What caused this movement?

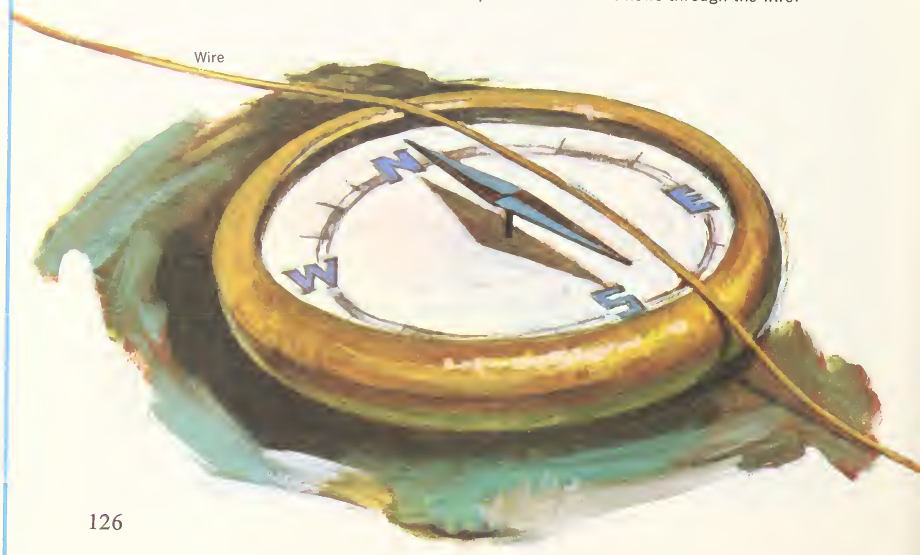
Force must be exerted on a compass needle to make it move. Since the needle is made of a magnetic material, steel, it will react to magnetic force. The current flowing through the wire must have produced the magnetic force to move the needle.

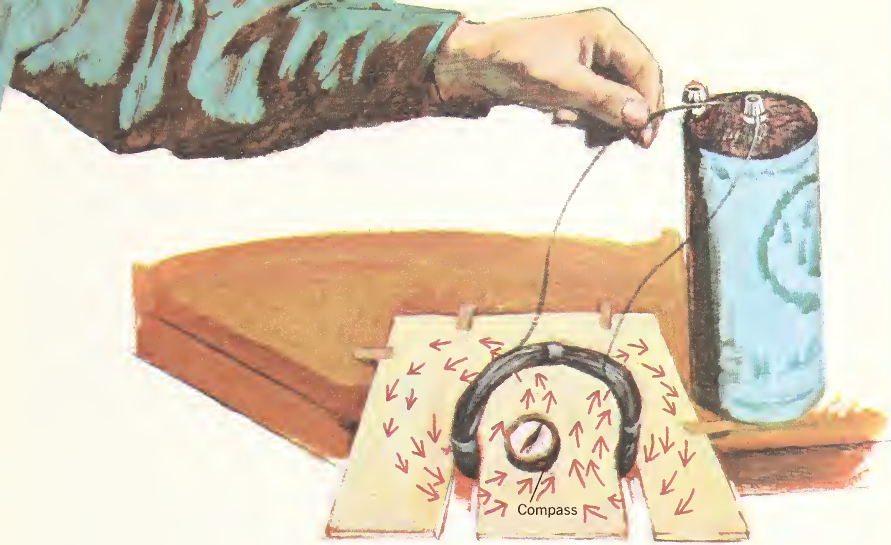
A flow of electrons produces the effect of magnetism.

Just how moving electrons produce a magnetic force is not yet fully understood by scientists. However, you can investigate the magnetic effects of a flow of electrons through a wire.

Wind a 6-inch-diameter coil of about 30 turns of bell wire. Cut a piece of cardboard as on the right. Place the coil in the cardboard slots and tape

What happens to the needle of the compass when current flows through the wire?





How is a magnetic field produced? What happens when the current is turned off?

the whole assembly to the corner of a wooden table. After placing a small compass on the cardboard, connect the coil to a dry cell for just a second. Note the direction the compass needle points while current is flowing in the coil. Break the circuit immediately after looking at the compass.

Remove the compass. Then draw the exact position of the compass needle on the cardboard. Repeat this procedure a number of times, placing the compass on different spots on the cardboard.

You will have drawn many arrows. These arrows show the **magnetic field** about the wires of the coil. A field is a region or space in which some activity takes place. A magnetic field is a space in which a magnetic force is experienced.

The magnetic field around the coil of wire has a definite shape and direction. Any substance that can be magnetized, such as iron filings, will be subject to a magnetic force in this field. The field exists only as long as current is flowing—that is, electrons

cardboard from the laundry is ideal. Be sure the two cuts are at least 6″ apart and 6″ deep.

Draw the diagram of the layout on the chalkboard and have the positions plotted on the board as you get your information from the cardboard. Perhaps you could ditto a sheet for each child.

Follow-Up: Pose the question:

- *How can we tell if this field is three-dimensional?*

Answers should lead to the torus or doughnut shape of the field. By raising the compass off the board at each position a child close up can record any changes in the orientation of the compass needle.

TEACHING SUGGESTIONS
(pp. 128–132)

LESSON: How is a magnetic field possible in a permanent magnet?

Background: Most iron is nonmagnetic. The reason is consistent with our general conceptual framework:

> "There is a basic tendency toward stability or equilibrium in the universe, and all objects in the universe and all particles of matter are constantly in motion."

Each atom of iron has its own magnetic field generated by the motion of its electrons. When iron is in the crystal state, as is a piece of solid iron, the arrangement of crystals is usually random. This arrangement produces millions of "patches," which are at all points of orientation to one another. In other words, there are random magnetic *domains*. The total effect of this random distribution produces no gross magnetic effect.

When this randomness (or balance in all directions) is under the influence of a magnetic field—for example, the magnetic field of the earth—the individual atoms of iron tend to orient themselves similarly to the model shown on page 130. In nature, this results in the formation of lodestones.

are moving in the same direction—in the wire. When the electric current in the wire is made to stop flowing, the magnetic field ceases to exist.

Now get a permanent bar magnet and place it on a piece of paper. Explore the magnetic field about the bar magnet with a small compass as you did before. Again draw arrows that indicate the positions of the compass needle.

The field of the permanent magnet also has a definite shape and direction. It resembles the magnetic field of the current-carrying coil.

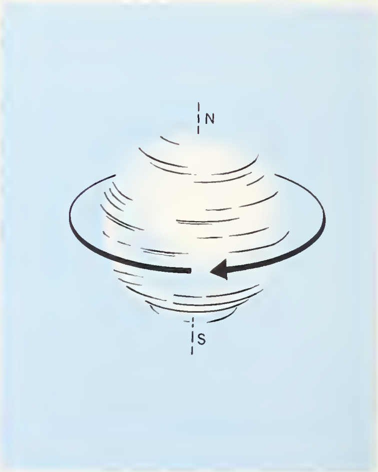
Permanent Magnets

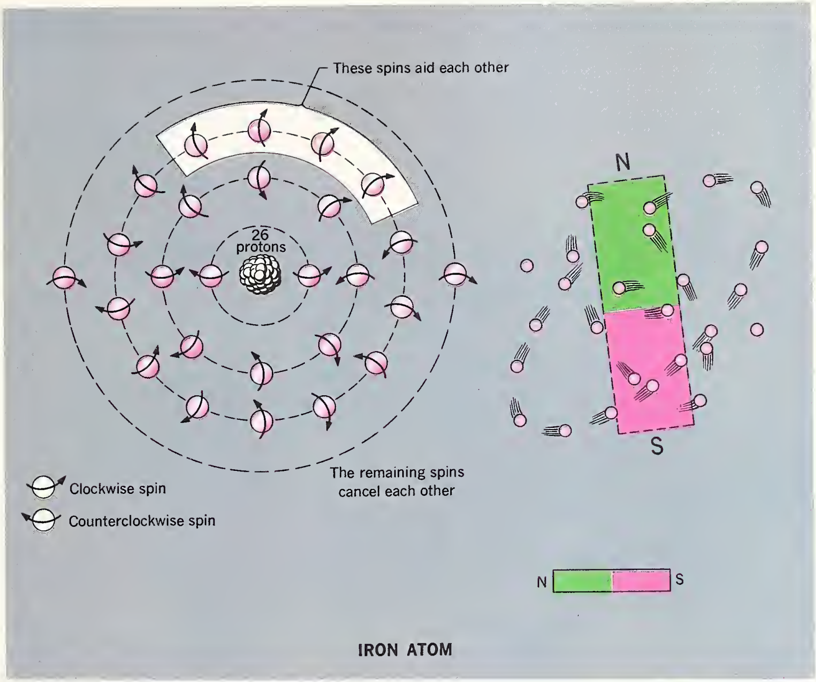
If a current of moving electrons, or electricity in motion, generates a magnetic force, what makes a permanent magnet? Strange as it may seem, the magnetism of a permanent magnet also is generated by the electricity of moving electrons.

You have learned that in the atom, the electrons not only revolve about the nucleus but also rotate on their own axes. In a great many materials, the rotations of the electrons are in directions that cancel each other. In certain other elements, such as nickel and

What does the compass indicate about the field?

A spinning electron generates magnetic force.





The bar magnet on the right serves as magnetic model for the iron atom.

iron, the spins of some of the electrons aid each other to produce the effect of moving electricity. This moving electricity generates a magnetic force.

Each atom in a piece of iron or nickel is, for the above reason, a tiny magnet. We could think of a small bar magnet as being the magnetic model of, for example, the iron atom.

This tiny bar magnet would be surrounded by the same kind of magnetic field you traced for the large bar magnet.

But iron does not normally exert a magnetic force. You know that paper clips that are made of iron do not attract or repel each other. How can this be explained?

In an electric conductor, the field generated by the internal motion of the electrons extends around the conductor and in turn can influence the arrangements of electrons and atoms in any iron near it. This is the basis for an electromagnet.

Learnings to Be Developed:

A magnetic field exhibits polarity.

A magnetic field depends on the orbiting electron spin.

The polarity of a magnetitc field depends on the direction in which electrons spin and orbit.

Developing the Lesson: Many scientific supply houses sell small models of the type shown on page 130, but you can make one for your demonstration quite easily. It is quite an effective model for the purposes of this lesson.

You will need a dozen or so corks and a dozen or more 1/2″ magnets of the variety used on school magnet boards or home memo boards. They are usually sold by the dozen. Cut your corks into circular wafers and place a small magnet on each.

Place the entire array in a shallow pan of water at random. The pan's surface area should be just a bit more than the total area taken up by the magnets and corks. This is to allow for some freedom of orientation in a contained area.

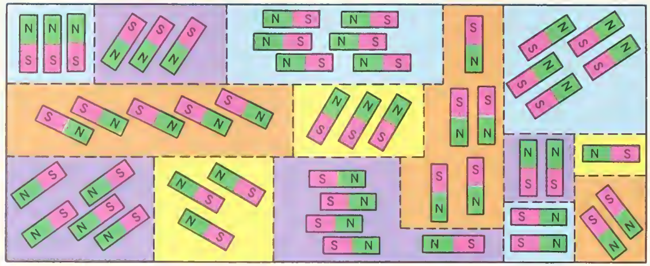
The individual floating magnets will align themselves and form a model of a "magnetic domain."

Discuss this domain as a model, and then ask:

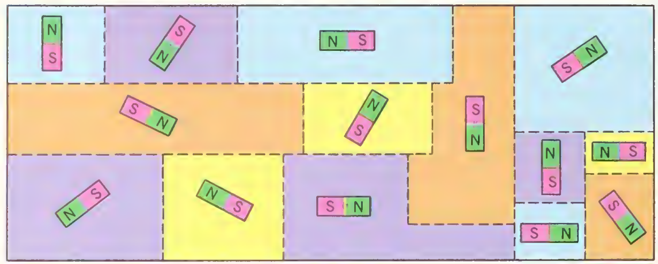
- *What would happen if all the little patches of iron like this model were to arrange themselves in a similar pattern?* (We would have a magnet model. The individual "atoms" could still move a bit if disturbed by outside force [strong magnet haphazardly stroked above the surface, physical vibration of the pan, etc.] This is a good model of soft iron.)
- *If we froze the water what would we have a model of?* (A permanent magnet. The "atoms" would not be too disturbed by outside forces unless the latter overcame the forces of orientation.)

Steel bonds are stronger than those of soft iron; hence, the molecular bonding is more permanent and the magnetic fields are more lasting.

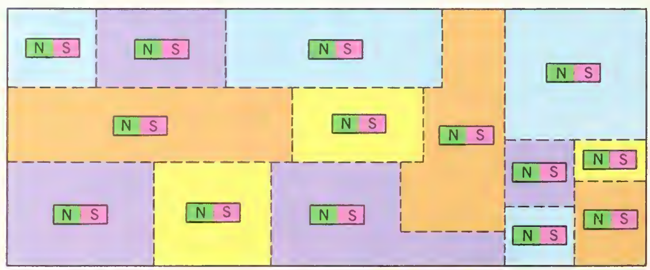
"Permanent," as used in this frame of reference, is a relative permanency. Do not leave the impression of irrevocable permanency, since heat, physical jarring, and stronger magnetic fields in the area can destroy the magnetic array.



Atoms magnetically arrange themselves in small groups.



Each group is now shown as a single bar magnet.



Under the force of a magnetic field, atoms arrange themselves into one magnetic group.

The answer is quite simple. The magnetic fields of the atoms cancel each other. The atoms in a piece of iron arrange themselves in small groups. Within each group the magnetic poles of the atoms all point in the same direction. A model of this group arrangement is shown in the first picture on the left.

Since the magnetic poles in each group point in the same direction, the magnetic fields of the atoms aid each other. For this reason, each group can be pictured as a single bar magnet.

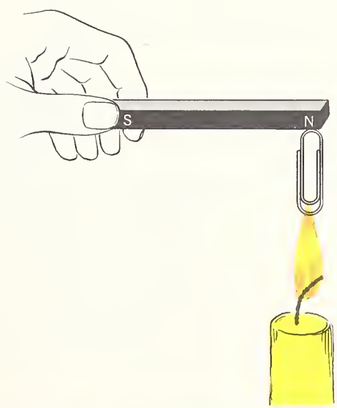
The groups are shown in the second picture as single bar magnets. But the poles of the single bar magnets point in various directions. Because of this, iron normally does not exert a magnetic force.

Suppose that an iron paper clip is brought near a permanent magnet. The strong magnetic field of the permanent magnet will rearrange the iron atoms as shown in the third picture. More of the atoms in the clip will magnetically point in the same direction. Their magnetic fields will aid each other. The clip, magnetized, now exerts a magnetic force. It is attracted to the permanent magnet.

To show that the atoms in iron must magnetically point in the same direction to exert a magnetic force, try this test. Hang a paper clip from a bar magnet. Heat the clip by means of a candle until it is very hot. The clip will fall from the magnet. Why?

When heat energy is added to matter, its atoms move much more rapidly. Because of this, the atoms will be so jarred that they will all point in different directions. Their magnetic fields will cancel each other. The heated iron will *not* show a magnetic effect.

Some permanent magnets are made of very hard steel. The atoms in steel are strongly held in position. Permanent magnets stay magnetized for a long time. All their atoms remain pointed in the same direction. They can be **demagnetized**—lose their magnetism—by being dropped. Sudden jars or great heat will rearrange the atoms.



Have a pupil report on the chapter "Degaussing the Fleet" in Francis Bitter's Magnets: The Education of a Physicist (a paperback from Doubleday, 65¢). The chapter is an entertaining and nontechnical story of the problems of protecting fleets of metal warships against magnetic mines

ADDITIONAL ACTIVITIES:

At times it has been reported that steel bars, pipes, and similar materials have been found to be magnetized when left in storage for a long period.

- *Can you explain how this might be possible?*

The molecular arrangement of the iron molecules slowly reoriented under the influence of the earth's magnetic field.

Large generator plants produce electricity in tremendous quantities and send it through conductors.

- *Do you think that the steel beams of the housing would be magnetized by long exposure?*

This is a good discussion question for the purpose of hypothesis building. The possibility of mass magnetism does exist here. However, it must be kept in mind that most generating power plants produce a current that is alternating—going back and forth in the conductor. Thus, any polarization that occurs when current is in one direction negates that polarization on the next change in current flow. Sixty-cycle changes occur, which in effect produce about 120 direction changes a second.

TEACHING SUGGESTIONS
(p. 132)

LESSON: What are magnetic poles?

Background: Somehow, but unrecorded by history, man discovered that the lodestone described by Thales, and its refinement, the magnet in the form of a needle, would align itself roughly at right angles with the sun's passage if the magnetic device were freely suspended. Around 1200 A.D., European navigators began to use such a device for guidance.

It is reported that centuries earlier the Chinese discovered this phenomenon, and the Arabs transmitted the information to Europe during the Crusades.

Early theorizing pointed to the heavens for the controlling force. Attraction in some celestial body was postulated by Peregrinus in the 13th century.

Learnings to Be Developed: Magnetic force is concentrated in the field about the poles of magnets.

Developing the Lesson: Previous learnings have sufficiently enforced a concept of North and South Magnetic Poles of the earth. Here, emphasis should be on the force that is concentrated at these terrestrial points.

Iron like that in paper clips is a soft metal. Its atoms are not strongly held in position. Because of atom vibrations, its atoms become magnetically mixed up even at low temperatures. Soft iron that has been magnetized will not hold its magnetism for very long.

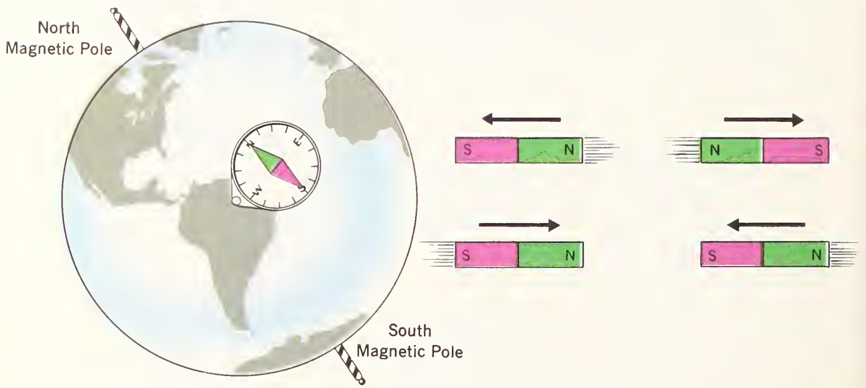
Magnetic Poles

You have used the phrase *magnetic poles* many times. You know that a magnet has two poles, a north pole and a south pole. The poles seem to be the centers of magnetic force. Can you tell how the poles got the names *north* and *south?*

A compass needle is a small magnet. When left alone, one end of the needle will tend to seek the North Magnetic Pole of the earth. For this reason, this end of the needle is called the *north-seeking pole*, or, for short, the north pole. Of course, the other end would be called the *south-seeking pole*, or the south pole.

In handling magnets, you cannot help noticing that like poles repel and unlike poles attract each other. In this respect, they are much like electric charges. But magnetism is a different property of matter from electricity. It is a property of electricity in motion.

Like magnetic poles repel each other. Unlike magnetic poles attract each other.



In the near future, every home may have a television viewer connected to the telephone, which will enable the speakers to see each other. On the right is a tape recorder, which magnetically records sounds on a tape that can be played many times and then erased and used to make other recordings.

Putting Electrons to Work

You now know that gases, liquids, and solids are states of matter.

You have learned that matter is defined by its properties—mass, electricity, and magnetism. The mass of matter is the center of its gravitational force. All matter can be broken down into elementary particles—neutrons, protons, and electrons. You also know that these particles are the centers of electrical and nuclear forces. You have learned many of the effects of these forces. Can you tell how scientists put these forces to work?

In the twentieth century the science of electronics has given rise to many discoveries, some of which led to the invention of radio, television, electric eyes, radar, tape recording, and, more recently, computers and automated machinery.

TEACHING SUGGESTIONS
(p. 133)

LESSON: How can we get electrons to do useful work?

Background: This short section introduces the field of electronics—the branch of physics that studies the emission, movement, and behavior of electrons in and *out* of conductors. Our approach here is simply to highlight some of the technology to which we are exposed.

Fundamentally electronics is based on an understanding of many aspects of the physical world. Much of the theory involved is old, but it is part of our understanding of the new. Much is so new that the latest engineering graduate is not aware of it. Newton's Laws of Motion apply in a vacuum tube of a radio or TV set. The lines of force described by Faraday operate in electronic devices as well as in a doorbell. Knowledge of the wave motions described by Huygens helps in the design of antennas.

Learnings to Be Developed: The properties of matter are gravitational mass, electricity, and magnetism.

Developing the Lesson: Make this a quick review lesson by recalling the concepts that by now should be familiar to the pupils. These all have a bearing on the study of electronics.

TEACHING SUGGESTIONS
(pp. 134–136)

Background: The most ancient computer is probably an *abacus*. The smallest business office usually has a comptometer or adding machine, which is really a computer. But in this section we are mainly concerned with the modern electronic computers.

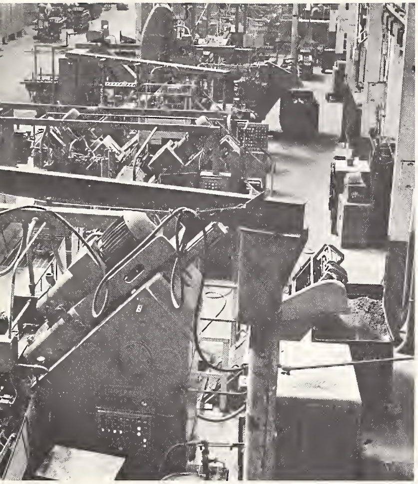
Great progress was being made during World War II in the production of computers that were more automatic and more versatile than earlier mechanical ones. Through the work of men such as John von Neumann, a mathematician, computers were designed after the pattern of the human brain cells. On the evidence that nerve cells can be either "on" or "off," excited or not excited, electronic units were made to substitute in wiring schemes for cells and performed as "on" or "off." Further developments in succeeding years brought solid-state devices as substitutes for vacuum tubes. Transistors, diodes, and photoelectric cells were developed that could operate without fatigue and with the speed of light.

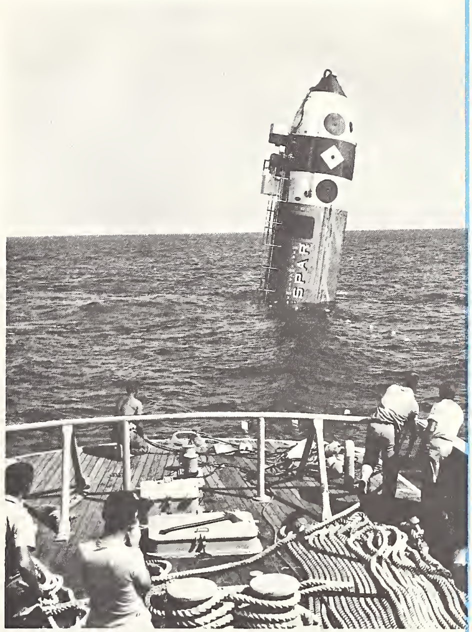
Today, electronic computers are of two types, *analog* and *digital*. The digital computer handles units, or bits, of information, usually in the form of numbers. Since

Computers

Electronics makes possible "memory systems" that can store large amounts of information very quickly. These memory systems are used to do an amazing variety of things.

In a computer, a magnetic tape holds information and supplies it on demand at a speed far greater than that of human calculation. For example, a computer can solve in an hour mathematical problems that it would take a skilled mathematician a lifetime to solve. The machines take over tiresome calculations and so relieve men to do more creative work. Electronic computers are now used to control other kinds of machines, to keep bank and payroll records, to store and produce inventory information on demand, to determine the probabilities on which insurance rates are based, and to perform many other tasks. This is why computers have been called "thinking machines."





Here you see two examples of automation. Above left, a factory assembly line is automatically controlled. On the right, a specially built ocean vessel is flipped on its end from a control ship. Once on end, it will be boarded by scientists who will conduct research projects from it.

Automation

Automation replaces the human worker with a machine that can do his job faster and more accurately. The machine is able to "see" errors and correct them. The machines become inspectors as well as workers.

The automatic washer is an example of a low degree of automation. It is loaded and turned on. It operates until it turns itself off. Computers show a high degree. They control and receive information from other machines and correct errors.

Automation with electronic controls can be utilized in almost every factory or process. Metal parts can be guided through hundreds of operations without a human touching them. Electronically guided tools can cut, drill, and weld. Automatic controls can adjust temperature, pressure, and oil flow.

switches or "cells" can be either on or off, the ideal base is two; therefore, the binary system is used. The analog computer handles continuous information, usually by converting electrical resistance of various circuits into a reading that is analogous to the situation being handled. A speedometer is something like an analog computer. It measures speed in terms of the current fed to the coils, which give a "readout" in miles per hour on a dial.

A large-scale computer can store more than a million bits of data in its memory and can turn out work faster than 500,000 men using desk calculators. The future for computers is even more promising. Machines are now taking over tasks that we previously accomplished with our brains. Computers provide us with the challenge of learning how to use machines fully and to our best advantage and further present us the greater challenge of discovering ways in which to use the human resources they displace. As we discover ways to utilize the manpower released by machines we can look forward to a brighter world of tomorrow.

Simulation: Computers can simulate conditions and problems of a space flight before the actual flight. They have been used to

simulate the sounds of the human voice and have composed human speech. Chemical reactions have been simulated without the use of chemicals.

In *real-time* computers the results are given fast enough to control an operation while it is in progress. Such uses include the actual analysis of data from orbiting spacemen and the production of orders for immediate implementation. Automation in a steel mill would be a *real-time* usage. Any change, at any point in the operation, would be recorded and analyzed, and corrections would be made immediately for the next step.

The largest usage in industry so far is known as *other-time* operations. Electric companies receive punched cards from meter readers who visit your home. These cards are fed to a computer, which ferrets out information on your present balance, computes your total bill, prints out the bill and envelope, inserts it, and prepares it for mailing—all in a fraction of the time it would take a staff of clerks to do, and with practically no errors and a very small staff.

The Future for Electronics

The number of ways in which electrons will be put to use in the future appears limitless. For example, electronics may be used one day to make highways automatic. Experiments have already shown that electronic devices can guide and control automobiles and prevent accidents. As scientists experiment in their laboratories, new kinds of electronic instruments are developed. These instruments lead to new discoveries about the laws of nature. These discoveries lead to new kinds of industry that branch out into new, more effective methods of communication, safer and faster travel, less expensive products through automated mass production, speedier ways to solve complex mathematical problems, and better ways to control and prevent human problems.

You now know a little bit about the science of electronics. The uses to which scientists put electrons are many. The science of electronics is vital to the exploration of outer space, to national defense, to education, to medicine, and to communications. If you choose a career in electronics, you will be working with the most powerful forces of nature—electricity, magnetism, and the mysterious force that holds together the parts of an atomic nucleus.

In your lifetime, automated highways may come into use. Once you enter such a highway, electrical controls take over and guide your car. What are the advantages of such a system?

Using What You Have Learned

1. Make a list of the ways in which gravitational force is put to work. A pile driver in which a heavy weight is dropped is one way.

2. Invite someone from your local telephone company to come talk about satellites and solar batteries. You might suggest that the speaker discuss other uses for solar batteries, such as how solar batteries can be of value to people in remote areas and whether solar batteries will someday replace present-day fuels as sources of energy.

3. Try making up small cells using various combinations of metals and chemicals. Try iron (nails or washers), copper, lead, zinc (galvanized washers or nails), tin (from tin-coated cans), aluminum (kitchen foil), and other available metals. Use salt water, vinegar, lemon juice, household bleach, and other liquids that are safe to handle. Determine which combinations will generate electrical energy by testing with your homemade galvanometer. Try to find out which are the negative and the positive terminals of the successful cells.

4. Get an unmarked bar magnet and a compass. How would you identify the poles of the unmarked magnet?

5. Read about Henri Becquerel, Ernest Rutherford, or Niels Bohr and write a report on his contribution to our knowledge of atoms, protons, and electrons.

6. Try this interesting puzzle. Get two of the same kind of large sewing needles. Magnetize only one as described in the activity on page 124. Now have someone mix up the two needles so that you cannot tell which one you magnetized. Using only the two needles, plan a test for telling which one is magnetized.

Most telephone company speakers are also prepared to talk on "Computer Speech" and "Conductors and Semiconductors." The talks and demonstrations are geared to audience level.

TEACHING SUGGESTIONS
(p. 137)

Background: The *Answers to Using What You Have Learned* are:

1. Unlimited possibilities, such as, coal chutes, pouring and siphoning liquids, falling water for hydroelectric power, sedimentation beds in water purifying plants, lobbing of mortar shells over embankments, etc.

3. Look up the *Electrochemical Series* or *Electromotive Series* in a physics or chemistry book. This list indicates relative activities of a series of metals arranged in the order of ease with which they give up electrons. The farther apart two metals are on the scale the more voltage will result in a voltaic cell.

4. The north-seeking pole of the compass would be attracted to the N end of the magnet. (But remember, the north-seeking pole of the compass is actually the S end of a magnet.)

6. One procedure would be to take one needle in your hand and lay the other on a desk. Test the attraction at the end of the needle on the desk and then at the middle. If force of attraction is the same at both locations, the needle in your hand is the magnet; if it is different, then the one on the desk is your magnet. Recall the shape of a magnetic field.

TEACHING SUGGESTIONS
(pp. 138—139)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned: This is a summary of the entire unit, with new words in boldface type.

Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390–393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

WHAT YOU KNOW ABOUT

Electricity and Electronics

What You Have Learned

The science of electronics studies the behavior of **electrons** and the forces of electricity and magnetism.

Electricity is present in the atoms of all matter. Every atom consists of a nucleus, made up of **protons** and **neutrons,** and electrons that revolve around the nucleus. Protons, neutrons, and electrons are called **elementary particles,** because it is believed that they cannot be further divided. The positive electrical **charge** of the proton and the negative electrical charge of the electron are called **elementary charges.** The neutron has no electrical charge, although it has **gravitational mass.** Unlike charges attract each other; like charges repel each other.

An atom that contains the same number of protons and electrons is **neutral.** For an atom to become electrically charged, electrons must be added or taken away, upsetting the balance between the positive and negative charges. The strong tendency of electrons to move away from the nucleus is called **inertia.**

Electricity is the movement of electrons through a **conductor.** A conductor is a substance through which electrons can pass easily. A substance through which electrons cannot pass easily is called an **insulator.**

The flow of electrons through a conductor produces the effect of magnetism around the conductor. The space in which this magnetic effect can be experienced is called a **magnetic field.**

Electricity, magnetism, and the force that holds together the nucleus of the atom are the most powerful forces in nature.

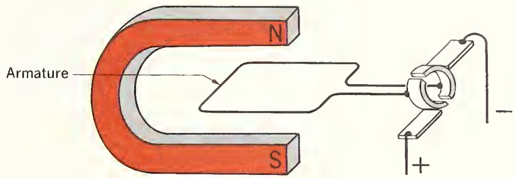
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

accelerators	galvanometer	neutrons
conductor	gravitational mass	photoelectric
demagnetized	inertia	protons
elementary charges	insulator	thermal energy

How Does a Motor Run?

From what you know about electricity, can you tell what happens when an electric current is sent through the wire? Trace this diagram in your notebook and then draw arrows to show the flow of electricity and the direction of movement of the rotating coil (armature).

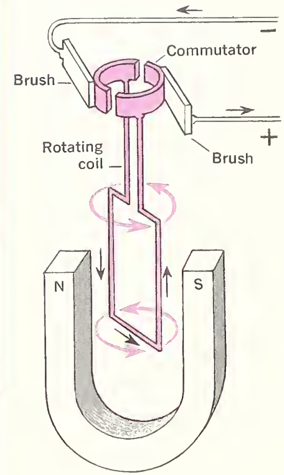


Complete the Sentence

Write the numbers 1 to 7 in your notebook. Next to each number write the answer that best completes the sentence.

1. An atom consists of a ___?___ and one or more ___?___.
2. The nucleus of an atom contains ___?___ and ___?___.
3. A proton has a ___?___ charge of electricity.
4. Unlike charges ___?___ each other.
5. An electric current is the flow of free electrons through a ___?___.
6. A battery changes ___?___ energy into electrical energy.
7. The flow of electricity through a conductor produces a ___?___ effect.

How Does a Motor Run?



When electricity goes through a conductor a magnetic field is produced about the conductor.

Complete the Sentence:

1. Nucleus; electrons
2. protons; neutrons
3. positive
4. attract
5. conductor
6. chemical
7. magnetic

TEACHING SUGGESTIONS
(pp. 140–141)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

You Can Use Your Electroscope: Rubbing the comb with fur will give the comb a negative charge of electricity. If the comb is then touched to the can, the can will be negatively charged. If the aluminum foil strips have a positive charge of electricity on them, touching the wire to them will cause them to collapse. If the strips have a negative charge already, touching the wire to them will cause them to spread farther apart. The fact that the position of the strips can be influenced in this way is evidence that an electric current is flowing through the wire.

Films:

Electricity: Principles of Safety (10 min., color, Coronet).

Electrons at Work (15 min., b/w, Young America Films).

How Electricity is Produced (11 min., color), Pat Dowling Pictures).

Magnetic, Electric, and Gravitational Fields (10 min., blw, Encyclopedia Britannica Films).

YOU CAN LEARN MORE ABOUT

Electricity and Electronics

You Can Make an Electroscope

An electroscope detects charges of electricity. To make one you will need a tall jar such as a jelly jar, copper or brass wire, pieces of aluminum foil, and a waxed cork or insulating wax.

Push an L-shaped piece of copper or brass wire through the cork or wax. Hang a string of aluminum foil from the lower end of the wire. Place the cork in the bottle. The cork or wax will prevent any charge from leaking away.

Now bring a charged object, such as a comb that you have run through your hair, near the bottle. What happens to the strip of foil? Can you tell whether the charge is like or unlike that of the strip?

You Can Visit

Your local electric utility company may have guided tours of their plants. At these plants you will see how electricity is produced. Ask the tour guide how atomic energy may be used to produce electricity. Would this be a more or less expensive operation than the way electricity is currently produced?

You Can Use Your Electroscope

By using your electroscope you can see that electricity flows through a conductor. Fasten the end of a wire to a can. Hold the other end of the wire to the electroscope you made. Charge the can by rubbing a plastic comb with fur and then touching the can. What happens to the aluminum foil? How does this show that electricity flows in a conductor?

You Can Read

1. *Electronics for Young People,* by Jeanne Bendick. Information about electronics and its applications.
2. *Wonder Worker: The Story of Electricity,* by Walter Buehr. Examples of electricity at work and the work of early scientists with electricity.
3. *The Bright Design,* by Katherine B. Shippen. The history of electrical energy.
4. *Electricity: The Story of Power,* by Arnold Mandelbaum. A history of electrical discovery and invention.
5. *Electrical Genius: Nicola Tesla,* by Arthur J. Beckhard. The story of the inventor of the alternating-current motor, the telephone amplifier, and other devices.

Additional Readings:

Experiments with Electricity, by Nelson Beeler and Franklyn M. Branley (Crowell, 1949). Twenty-five projects using simple equipment, with explanations of underlying principles.

The Boys' Book of Radio, Television and Radar, by Leonard Bertin, (Roy, 1958). Electromagnetic theory and standard electronic devices.

Electromagnetic Waves, by Robert Irving (Knopf, 1960). For the advanced student.

Electronics, by Robert Irving (Knopf, 1961). Basic electric and electromagnetic principles, basic components of electronic equipment, and application circuits.

Understanding Electronics: From Vacuum Tube to Thinking Machine, by John Lewellen (Crowell, 1957). Includes detailed study of electron theory in relation to atomic structure.

Power Unlimited! by Abraham and Rebecca B. Marcus (Prentice-Hall, 1959). Advanced and thorough; excellent on electricity.

The Real Book of Electronics, by Edward Stoddard (Garden City, 1956). Fairly simple.

KEY CONCEPTS

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 4. All objects in the universe and all particles of matter are constantly in motion; man has discovered and stated the laws governing their motion.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. Over the years, a number of ideas or models have been developed to explain the motion of celestial bodies.
2. Models of the solar system must explain the observed motion of bodies in it.
3. Both earth-centered and sun-centered models can be used to explain many motions in the solar system; however, the sun-centered model is simplest.

5

Other concepts appear under 'Learnings to Be Developed' in each lesson found in the Teaching Suggestions.

Astronomy

Models of the Solar System

Locating Things in Space

Finding the Sizes of Objects in Space

Viewing the Universe

4. Parallax makes it possible to estimate distances.
5. Distance and sizes may be measured by triangulation.
6. Many facts about the sun and its nine planets have been discovered by indirect methods of measurement.
7. The sun is only one of many stars making up the Milky Way Galaxy.
8. The universe is made up of many galaxies.

PROCESSES:

- Observing—Pages 145, 146, 147, 150, 151, 155, 162, 164, 168, 169, 172, 174, 175, 187.
- Experimenting—162, 168, 172.
- Comparing—145, 146, 147, 150, 151, 155, 159, 162, 164, 168, 169, 172, 174, 175.
- Inferring—147, 151, 155, 158, 162, 168, 169, 172, 174, 175.
- Measuring—155, 162, 164, 168, 169, 172, 174, 175.
- Classifying—184, 185.
- Selecting—145, 146, 158, 159, 187.
- Demonstrating—150, 151, 155, 164, 165, 168, 169, 174, 175, 187.
- Explaining—146, 147, 158, 160, 164, 165, 168, 169, 170, 187.
- Hypothesizing—146, 147, 163.

TEACHING SUGGESTIONS
(pp. 144–145)

LESSON: How are models used in science?

Background: In this section, we try to impress upon the pupils the impossibility of making direct measurements of astronomical objects. Objects on earth can always be measured directly, or their sizes can be deduced by indirect measurements, but astronomers have always had to work at great distances. It is only very recently that space probes have enabled scientists to gather information more directly than through telescopes.

In discussing astronomical observations, it may be noted that extremely precise measurements can be made using very simple instruments. The ancient Assyrians, for example, had a very accurate calendar based on the motions of the moon, and they were able to predict eclipses of the moon 19 years in advance. The visible planets also have regular periods, and they follow much the same path through the sky as do the sun and the moon.

Learnings to Be Developed: Over the years a number of ideas or models have been developed to explain the observable motions of celestial bodies.

Objects in the sky always have fascinated man—from earliest times to the present. The stars, moon, sun, and planets have been studied by careful observers for thousands of years. In this unit, you will discover some of the methods astronomers use to answer questions about objects millions of miles away.

Models of the Solar System

To study the structure of an insect, you can catch a fly or a beetle and observe it carefully with a magnifying glass. To learn about its behavior, you can do many things to it. You can put it in a cold place, turn it upside down, or shine a light on it.

You can learn about many objects on earth—insects, flowers, magnets, tuning forks—by examining them closely or experimenting with them, but it is not possible to learn about the stars and planets this way. These objects can only be observed from great distances.

How do these pictures show the direction the sun seems to move across the sky?

Some observations of stars and planets are quite simple and were made thousands of years ago. Every clear morning, the sun may be seen in the eastern sky. It appears to move slowly toward the west, where it sets in the evening. Each day the movement is repeated. On some clear evenings you can see the moon in the eastern sky. In what direction does it appear to move across the sky? How long does it take? In what direction do the stars appear to move across the sky? How long do they take to move? How can you explain these motions?

To explain the motions of the sun, moon, and stars, you must have ideas about where each is located in space. You must also have ideas about their movements in space. Since the moon, sun, and stars are so far from the earth, it is impossible to get these ideas by observing their positions and movements directly. You have to imagine where they are located in space and how they move. When you have a set of such ideas, you have a *model*. Over the years astronomers have developed several different models to show relationships among the sun, moon, and planets.

Developing the Lesson: Base the discussion on the pupils' awareness or knowledge of the motions of the sun, moon, and planets across the sky. Try to develop a rough model of the solar system (without being explicit about what you are doing) based on the facts known or guessed by the pupils when discussing these motions.

The pictures on page 145 give a clue to your procedure. Ask questions such as:

- *Where does the sun first appear in the sky?*
- *Where does it set?*
- *If we simply observed the sun daily, what conclusions could we come to?*
- *Do we need any more evidence to construct a model showing the relationship of the earth and the sun?*
- *Criticize the model we just described. Do the motions of the stars support our model or do they contradict it?*

When you have carried the discussion as far as you can without anticipating the rest of the unit, conclude by pointing out that scientists, by following the process the class has just concluded, have been able to learn more or to plan new observations and experiments to answer questions.

TEACHING SUGGESTIONS
(p. 146)

● LESSON: How are models used for scientific discoveries?

Background: The use of models is widespread in all of science. Very simply, a model is an explanation for all the observed facts.

Learnings to Be Developed:
Models are attempts to group facts together, to correlate what is known with what is unknown.

Models of the solar system must explain the observed motions of the bodies in it.

Developing the Lesson: Begin with the meaning of the word "model." Have the pupils explain what the word means to them, and have them give examples of models. The common meaning they will associate with the word is that of small scale toys–model airplanes, model trains, and so forth. If there is available a model of a molecule or atom made of wire and balls, have them explain why this is a model.

• *What purpose would such a model serve a chemist? Is it an accurate reproduction, such as a model train might be?*

Finally, discuss models of the solar system and why astronomers have constructed such models.

As each model has been developed, it has been used to answer such questions as: Why do these bodies appear to move from east to west across the sky? Why do planets appear brighter at some times than at others? What causes the seasons?

Models may take different forms. At first a model may be ideas carried around in the head of its inventor. Later he may describe his model by writing about it. He may draw a diagram to show what it is like. He may actually construct the model to demonstrate how his ideas can be used in giving an explanation.

Making Models to Explain Ideas *

You probably have made models of the planets to show their relative sizes. You also may have hung them from the ceiling of your classroom to show their arrangement around the sun. You made these models after studying a number of modern ideas about the planets. The ideas about the sun and its planets that we accept today have been developed only within the last four hundred years. Four hundred years is a short time compared with the many thousands of years that human beings have been on the earth.

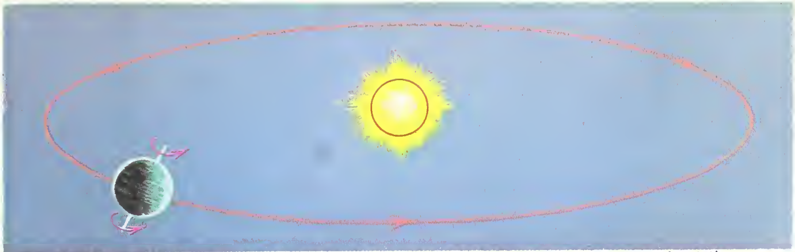
Make a list of the things that you on the earth can observe about the sun, moon, and stars. Be sure that your list includes only what you actually can observe. Include items that you will be able to observe over a one-year period.

Suppose this were all that you knew about the sun, moon, and stars. In other words, suppose you lived several thousand years ago. How would you explain the things you observed? Think up ideas that would help you explain them. What kind of model can you construct? Where will you put the sun in your model? Where will you put the earth and the moon? Is it possible to think of more than one model?

On the top of the next page you can see a model that can be used to explain a number of events. The sun does not move in this model. The earth spins on an axis. It makes one complete turn every twenty-four hours. Use a globe or a ball to explain how this model accounts for the rising of the sun, its apparent movement across the sky, its setting about twelve hours after rising, and its rising again the next morning.

Now make a model in which the earth stands still. Use it to explain sunrise, the movement of the sun across the sky, sunset, and another sunrise. Does your new model account for the same observed facts as the first model? How does it?

Pages 146 and 147 discuss the development of models of the solar system from the available observations. If you choose to discuss this, be sure the pupils offer only observed facts, not derived facts that they may have read.



In this model, the sun stands still, and the earth spins on its axis and turns about the sun every 24 hours. How does this model account for the rising and setting of the sun?

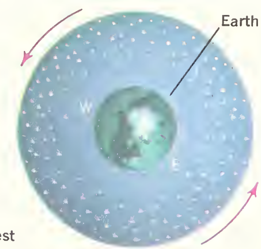
Which model gives the better explanation? Neither one! For the observations that you set out to explain (sunrise, sunset, sunrise again), both models are "right." Both can be used to explain what you see. In fact, both of these models have been used. Why do we accept the one we do today?

What evidence obtained by actual observation can be used to prove that the earth rotates?

An Earth-Centered Model

When you look up at the stars at night, you feel as though you are at the center of all you observe. It was reasonable for early astronomers to think of a model in which the earth was the center of everything. You cannot detect any movement of the earth. It seems to be motionless. Therefore, a description of a motionless earth at the center of everything seemed to be quite proper.

To complete this model, early astronomers imagined the earth to be surrounded by an enormous shell or sphere. The stars were set within this sphere. The sphere made one complete turn around the earth every twenty-four hours. This reasoning accounted for the apparent daily movement of the stars across the sky from east to west.



In this model, a sphere of fixed stars revolves every 24 hours about a motionless earth.

TEACHING SUGGESTIONS
(pp. 147–151)

LESSON: How well does the earth-centered model of the solar system account for the observed facts?

Background: Treat pages 147 through 151 as a unit, and build on the concepts of a model that you have already developed. The main point is to explain as well as possible the *observed* motions of the sun, moon, and planets. Question any statement made by a pupil that you suspect is based on his reading or that cannot actually be made as a result of naked-eye observation.

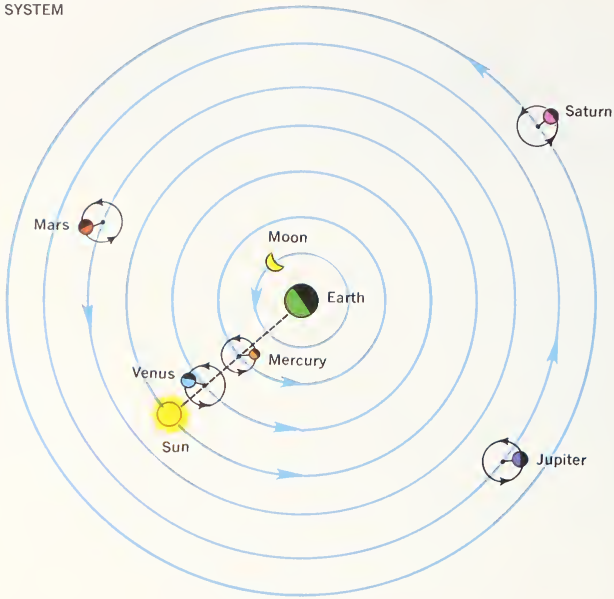
The purpose of this section of the text is to contrast the earth-centered model with the sun-centered model of Copernicus, which the pupils will study next. As a matter of fact, the earth-centered model does appear more obvious and conforms better with the facts of daily life than does the sun-centered model, and the idea of the sun's circling the earth daily should not be dismissed lightly. Treat it seriously in class. If, for pedagogical reasons, you should assert that the Ptolemaic model is true and challenge the pupils to refute you, they will not be able to do so—at least, not on the evidence of their own unaided senses.

A brief introduction to the astronomy of the ancient Greeks will give the youngsters an understanding of the historical development of astronomy.

The greatest of the Greek astronomers was Hipparchus, who lived in the 2nd century B.C. and had an observatory on the island of Rhodes. Hipparchus discovered the actual distance of the moon from the earth by the method of measuring its *parallax,* which is to be studied in greater detail later in this unit. He also made the first accurate star catalog, accurately measuring the positions of over 1,000 of the brightest stars in the night sky and inventing his own instruments to do so. He also indicated the brightness of each star by the system of magnitudes still used today. In this system, the brightest stars have a magnitude of 1. Stars one-half as bright have a magnitude of 2, and so on, until stars of magnitude 6 are reached, which are barely visible to the eye.

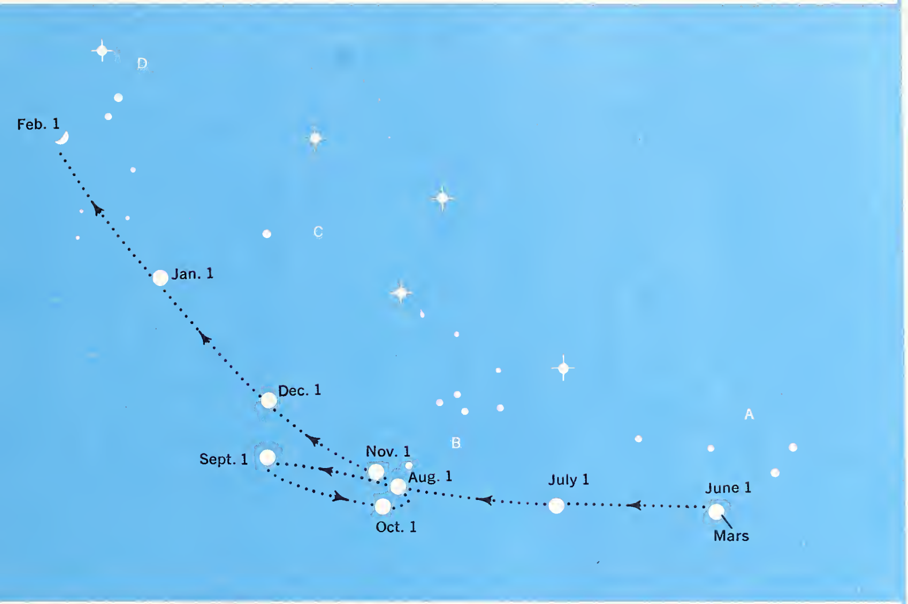
Hipparchus also plotted the positions of the planets and was the originator of the system of epicycles used to describe their apparent retrograde motion, a system that Ptolemy elaborated and which is called after him. It would be too simple to state that the Greeks actually believed that the planets followed the complicated

PTOLEMAIC SYSTEM



The diagram above shows one such earth-centered model. This is called the **Ptolemaic** (tol-uh-MAY-ik) model. It was invented by Claudius Ptolemy (TOL-uh-mee) about eighteen hundred years ago to explain the movements of the sun, moon, and planets around the earth. In this model, the moon revolved around the earth once in about twenty-five hours. The sun and stars made the trip in twenty-four hours. Why did the moon seem to move more slowly than the sun and the stars?

However, the planets presented a problem. Their motion was not the same as that of the stars. Although the planets revolved around the earth along with the stars every day, they did not always appear in exactly the same positions among the stars.



The diagram above shows how one of the planets, Mars, may shift its position among the stars over a period of nine months.

You will see that on June 1, Mars was near the stars in Group A. By July 1, its position had shifted eastward so that it was near the stars in Group B. By August 1 it had moved a little beyond this group of stars, and by September 1 it had moved even farther eastward.

But look what happened between September 1 and October 1. The position of Mars shifted *backward* toward the west. Then, between October 1 and November 1, it shifted again toward the east. Finally, between November 1 and February 1, it shifted eastward from a position near the stars in Group

paths described by epicycles revolving within epicycles. The Ptolemaic system was mainly a geometrical construction which *described* the motions of the planets, not acco*unted* for those motions. And the reason that the motions of the planets had to be described so accurately was to enable astronomers and astrologers to foretell their future positions. The more accurately the astrologers could predict the future positions of the planets in the heavens, the more accurately they believed they could foretell the future of individuals' lives.

Ptolemy was born about 300 years after Hipparchus, and all his work was based on Hipparchus' writings. He proceeded to bring Hipparchus' star catalog up to date and to correct the discrepancies between the predicted positions of the planets and their actual positions. Hipparchus' system of epicycles was not too exact, and Ptolemy improved upon this system. In the end, by following his geometrical constructions, other astronomers were able to predict the positions of the planets accurately for about a century before the discrepancies became too large.

Ptolemy's book on astronomy, *Megale mathematike synthaxis*, was translated into Arabic and

called by the Arabs the *Almagest*, by which name it is known today. It was through inaccurate Arabic translations, which also included additional and misleading information, that Ptolemy's work became known to the Western world.

Learnings to Be Developed: The earth-centered model of the solar system does account for the observed positions of the planets.

Developing the Lesson: If the pupils have not already done so, have them make a list of the visible motions of the sun, moon, and planets. The sun rises in the east and sets in the west every day. It rises higher in the sky as June 21 approaches and then retreats again to a minimum point on December 21. The moon rotates around the earth once every 29 days, while the planets follow courses along the *ecliptic*. The text describes the retrograde motions of Mars and the other planets, motions that are not immediately obvious but which can be accepted as true (and would be if the pupils were to keep accurate records). The daily amount of retrograde motion is, in fact, quite small and does require careful observation.

The forward motion among the fixed stars of the planet Jupiter,

B to those in Group D. It was because these bodies shift their positions among the stars that they were called *planets*. The word *planets* means "wandering." The backward shift in position of a planet is called **retrograde motion** (RET-ruh-grayd).

The Ptolemaic model had to explain two things about the observed motion of planets. First, it had to explain why they moved eastward among the stars. This could be done by having them revolve around the earth a little more slowly than the stars revolved. Second, the model had to explain retrograde motion.

As you can see in the diagram on page 148, Ptolemy had the idea that

each planet went around the earth in two circles. One was the large circle that carried it completely around the sun. The other was a smaller circle, the center of which was on the larger circle. The small circle was called an **epicycle** (EP-uh-sy-k'l). As Mars revolves around the center of the smaller circle it would appear to be going backward at times. You can demonstrate this to yourself in the following manner. Stretch out your arm and hold a pencil in your hand as the boy in the picture on page 150 is doing. As you turn around move the pencil in circles. You will see that the pencil seems to be forming loops as you turn around. You will also see that at times the pencil appears to be moving in the same direction you are. At other times it appears to be moving backward. It was in a way like this that Ptolemy used his model to explain retrograde motion of planets.

There was another fact about Mars that astronomers had observed. At the times when Mars was retrograding (moving backward), it appeared to be brightest. How can the Ptolemaic model be used to explain this interesting fact about Mars?

Ptolemy was able to build a model of the universe that fit all the facts known in his lifetime. His model seems complicated today, but it was a

Claudius Ptolemy was a Greek astronomer.

great achievement. Ptolemy's model, with the earth perfectly still and at the center of the universe, accounted for everything that could be seen with the unaided eye. This model was widely accepted for about fifteen hundred years. No one really challenged it until the sixteenth century.

The Ptolemaic model of the universe also may be called the Ptolemaic theory. You remember that *theories* are sets of ideas that explain how or why things happen as they do. How are models different from theories?

for example, amounts to about one minute (1′) a day. This distance is about 1/30 the diameter of the moon. This forward motion gradually slows down and stops, and Jupiter then begins to move in a retrograde direction and at an apparent rate of motion among the fixed stars amounting to about ½′ before it recommences its forward motion.

The Ptolemaic model can be developed in two stages. First, describe the simple model of planets moving with a circular motion; second, add the complications provided by the observed retrograde motions.

• *Can you account for the retrograde motion of the planets in other ways than by hypothesizing epicycles?*

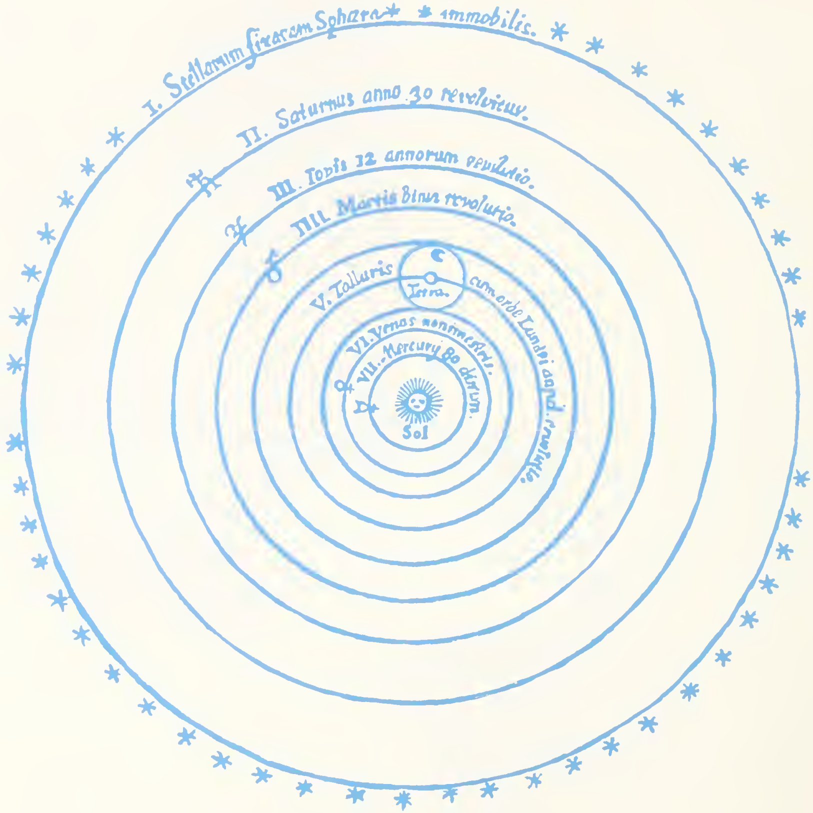
The answer is, of course, the Copernican model, but if pupils get involved in the description of the Ptolemaic system, they may not think of it.

TEACHING SUGGESTIONS
(pp. 152–156)

● **LESSON:** How does Copernicus' model account for the observed motions of the planets?

Background: One purpose of this unit is to set up two contrasting explanations for the same observed facts and see if the pupils can make a choice between the two explanations. It is an exercise in framing hypotheses, even though everyone "knows" the earth revolves around the sun. Nevertheless, as much as possible, the contrasting models of the solar system should be treated as if each were equally true, or at least equally capable of explaining the observed facts.

If you divide the class into two groups, one group pro-Ptolemy and the other group pro-Copernicus, you might better show the pupils how well both models explain the observed facts. This debate can better take place toward the end of this section, after the entire class has discussed both theories in detail and are in a position to argue the merits of each model. Of course, it would have to be agreed that only naked-eye observations are admissible as evidence.



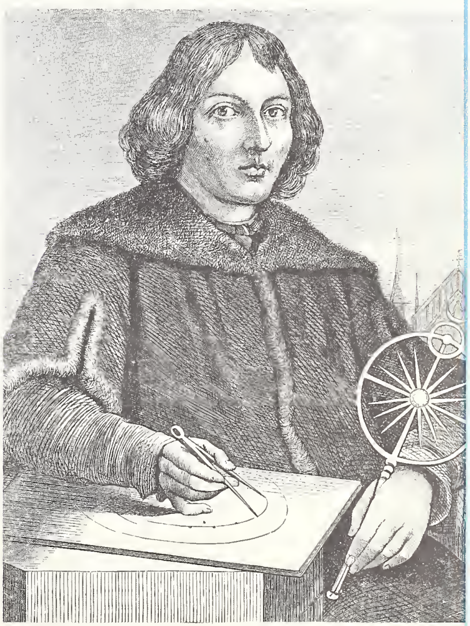
THE WORLD OF COPERNICUS

A Sun-Centered Model

In 1543, Nicolaus Copernicus published a book in which he suggested that the sun, not the earth, was at the center of the solar system. Copernicus was not the first to hold this view. In fact, some scientists who lived before Ptolemy thought the sun was at the center. But Copernicus' theory came after a very long period in which most people considered the earth to be at the center of everything. Copernicus looked at the universe in a new and bold way for his time.

How is a new theory tested? First, Copernicus had to show that his theory accounted for the same facts as did Ptolemy's. And, indeed, you can explain day and night without moving the sun around the earth each day: you can spin the earth instead. But what about the motion of planets? What about the motion of Mars? You have seen how Ptolemy's circles accounted for the fact that Mars seemed to retrograde and to get brighter at times. Can you use Copernicus' model to explain these two facts?

Copernicus was born in Poland on February 19, 1473, and died there on May 24, 1543. His real name was Niklas Koppernigk, but, like so many others of that time, he transformed it into a Latin name. He came from a well-to-do family —his uncle was a bishop—and he had the opportunity to study. He spent 10 years in Italy, studying mathematics, medicine, astronomy, and canon law. It was in Italy, apparently, that he had the first glimmerings of his theory of the universe. He returned to Poland, became a canon in the Roman Catholic Church, and served his uncle as his physician. His main task, however, was to perfect his theory as far as possible, and he devoted most of his time to this task for 30 years.



Nicolaus Copernicus, a sixteenth-century astronomer, overthrew the age-old belief that the earth was fixed at the center of the universe. He formed the general plan of the solar system which today's scientists accept. On the left, you see a drawing of Copernicus' idea of the universe. Can you describe it?

It is usually thought that Copernicus merely said that the planets rotated around the sun—*fiat dixit,* and for this he became famous. Hardly. He set himself to show mathematically that his system would account for the observed facts at least as well as the Ptolemaic theory and, in addition, account for additional facts concerning the motions of the planets that the Ptolemaic theory took into account not at all or only with great difficulty.

Criticisms raised against Copernicus' theories were: If the earth revolved about the sun, why didn't the stars seem to show parallax; and why wasn't the motion of the earth apparent in some way? The first point wasn't settled until Bessel was able to show that the star 61 Cygni had a definite parallax (which could be the result only of the earth's motion about the sun). The second objection wasn't met until Foucault's experiment in which he suspended a pendulum from the dome of the Parthenon in Paris. As the earth turned under the pendulum, the arc of the pendulum seemed to turn in a great circle over the floor of the building.

One concept that the pupils may find difficult to grasp is that of retrograde motion, which merely means backward motion. In the

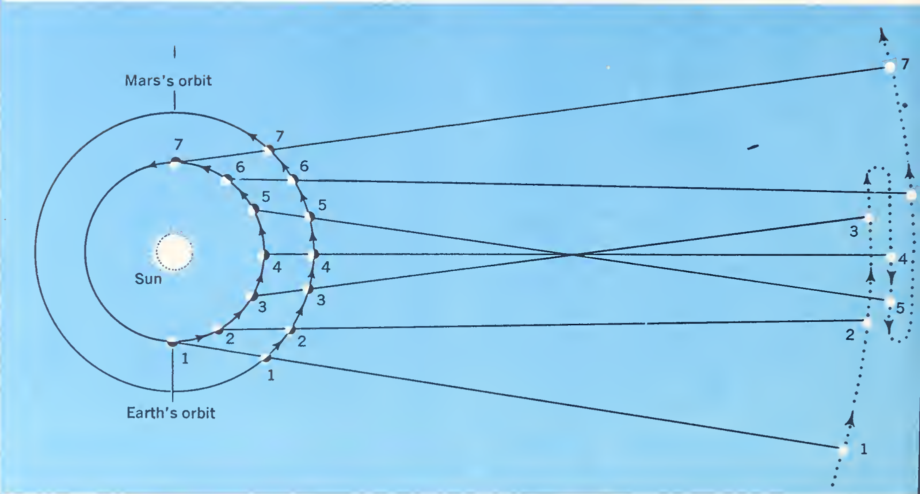
context of this lesson, it is the *apparent* backward motion that is discussed. This apparent backward motion is quite common in these days of fast transportation, and the pupils will have observed many examples of this phenomenon without being aware of it. The text on page 156 mentions the apparent backward motion of one train relative to another. Another and perhaps more common example is that of two automobiles starting up at the same time from an intersection. One car will accelerate faster than the other, and the passengers in the faster-moving car will have the illusion that the slower car is moving backward. Of course, it isn't. Another common example is the apparent backward motion of the more distant scenery compared to objects close at hand when one is driving along a highway. This motion is also an apparent retrograde motion.

Learnings to Be Developed:

Retrograde motion is illusory and based on the relative positions of the planets as they revolve around the sun in different orbits.

Both earth-centered and sun-centered models can be used to explain many motions in the solar system.

The sun-centered model is the simpler.



Retrograde Explained by Copernicus' Model

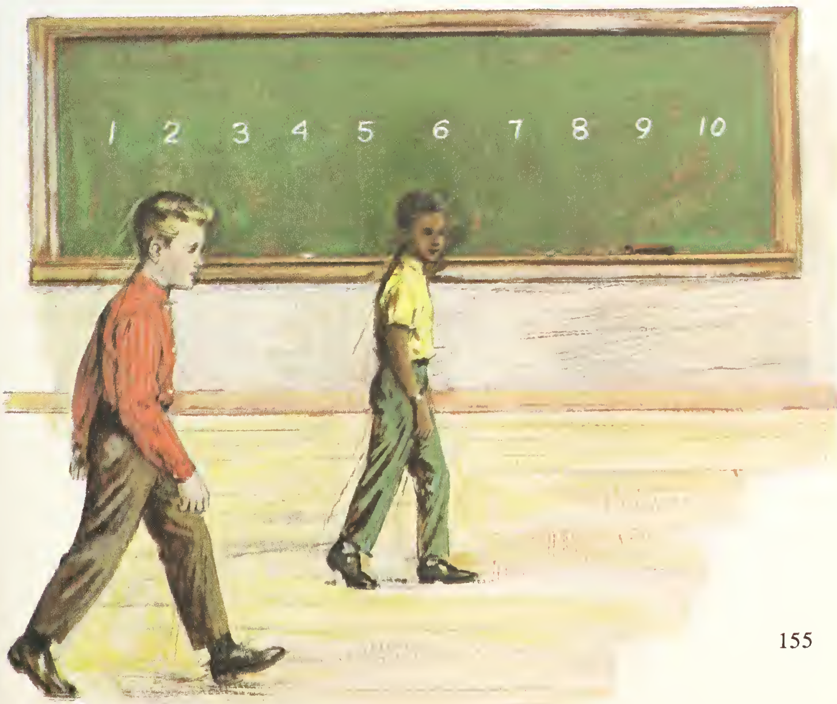
In the diagram, you see the orbits of earth and Mars around the sun as Copernicus thought of them. The numbers on the earth's orbit show the positions of the earth at different times, one month apart. (Similarly, the numbers on Mars's orbit show the positions of that planet on the same days.) Now look at the line connecting point 1 on the earth's orbit with point 1 on Mars's orbit. This line is extended out to the stars. It shows where Mars would be seen against the background of stars by an observer on earth.

Look at the points numbered 2 on both orbits. The line through these points shows where Mars is seen from the earth one month later. After still another month, Mars is seen along the line through points 3. During this three-month period, Mars seems to move across the sky from west to east. Notice that the point where Mars seems to be depends on *both* the position of the earth *and* the position of Mars.

Now look at the positions in the fourth month. The line through point 4 is extended to the stars. But point 4 among the stars is *behind*, or west of, point 3. To an observer on the earth,

Mars has moved to the west—or backward—during this month. Of course, Mars has not really moved backward at all. It just seems that way to an observer looking at it from the earth.

Here is an activity that will help you understand this idea. Have one person stand about ten feet from the chalkboard at the front of the room, while you stand about fifteen feet away from it. Put as many numbers as you can on the board, about one foot apart, starting with 1. Now the person is to walk slowly in front of the board toward one side of the room, keeping about ten feet from the chalkboard all the time. He represents Mars. The numbers on the board represent stars. You will represent an observer on the earth. After the Mars person has walked about four steps, you can start walking about twice as fast as he is walking. In other words, you take two steps while he is taking one step.



Developing the Lesson: Begin by discussing the meaning of the word *retrograde* and ask the pupils if they can give examples of retrograde motion similar to those discussed under *Background*. Then go on to have the pupils perform the activity suggested on page 155. Be sure that the pupil near the chalkboard walks slowly and that he starts before the pupil farther from the board.

ADDITIONAL ACTIVITIES:

If a very bright light with a sharply focused beam is available (from a slide projector or movie projector, for example), the following experiment can be very effective in showing retrograde motion as described in the text and shown in the illustration on page 154.

Out of a large piece of cardboard, cut two concentric circles with a sharp razor blade. This must be done accurately enough to enable the inner circle to revolve inside the outer circle. Attach dowels of different heights to each circle, each dowel to represent a planet. The light is then projected so that shadow images of the dowels are thrown upon a screen or wall. When the circles are rotated (by turning them by hand) so that they reproduce the motions described in the text, it is much easier to explain the apparent retrograde motion of the outer planet.

TEACHING SUGGESTIONS
(pp. 156–157)

● **LESSON:** Which model better accounts for the observed motions of the sun, moon, and planets?

Background: Here we point out that the two models explain the facts equally well. The main virtue of the Copernican theory was that it is simpler.

It was not until additional information was gained because of the invention of the telescope that the Copernican theory was shown to be the correct theory.

Learnings to Be Developed: The two models account equally well for the motions of the sun, moon, and planets.

Developing the Lesson: The material in this unit so far can now be summarized and some conclusions drawn. As suggested before, you might now divide the class into two groups, pro-Ptolemy and pro-Copernicus, and have each group attempt to show the virtues of its own model and the defects of the other. In ending the discussion, be sure to point out how well each theory accounted for the facts, and that it required additional information before scientists could choose one over the other on a basis other than preference for simplicity.

During your walk, notice what number you see behind your friend as you look toward him at the chalkboard. Notice that when you start to pass him, it suddenly appears as though he has stopped. Then it appears as though he were moving backward. The numbers seem to reverse direction.

In the solar system, when the earth passes Mars, Mars seems to move backward against the background of stars, as you saw in the diagram on page 154.

Still another way to think of this idea is to imagine yourself in a train on a track in a station next to another train. Neither train is moving. Now your train starts to move forward slowly and smoothly. You may not feel the movement, and you may not realize that your train has started. What you appear to see is the other train moving backward. Actually, your train is moving forward while the other train is standing still.

Both the earth and Mars move "forward." But the earth moves faster. When we pass Mars it looks as though Mars is moving backward.

You have seen how Mars's backward motion is explained by the Copernican theory. But there is a second puzzling fact about the appearance of Mars. Mars seems brightest in the middle of its backward motion. You have seen how Ptolemy explained this fact with his epicycles. As Mars moves backward, it loops in toward the earth. As it gets closer to the earth, it appears brighter. How can the brighter appearance of Mars when it seems to move backward be explained by the sun-centered model? Study the diagram on page 154 to figure out the answer.

Which Theory to Choose?

Both the earth-centered model and the sun-centered model account for the facts you have read about so far. Both models predict where a planet will be seen. Both models account for the motions of the sun, moon, and stars. When Copernicus suggested the new model, most astronomers saw no special reason for accepting it. Ptolemy's model accounted very well for all the facts. Why change theories?

Copernicus liked his theory better than Ptolemy's because the sun-centered model had fewer circles. Copernicus thought of the sun at the center of the universe with the planets moving around in perfect circles. Ptolemy thought the earth was at the center and had to put the planets on circles drawn on circles. The simpler model of planetary motion seemed a better idea to Copernicus, and this was the only reason given for accepting the new theory. An astronomer in 1550 would choose the Coperni-

Above is Tycho Brahe in his observatory in 1602. Above right is Johann Kepler, a German astronomer, discussing his discovery of planetary motion with Emperor Rudolph II. Below is Galileo. Learn about the findings each of these men made and how the findings have helped us to understand the universe.

Brahe accomplished his work before the telescope had been invented.

can model if he liked a simple system. He would choose the Ptolemaic model if keeping the earth at the center of everything were more important to him than a simple system.

Nearly 300 years after the death of Copernicus, scientists found other reasons for accepting the Copernican model. You will discover some of those reasons as you read on in this unit.

Galileo founded the modern science of mechanics, which showed how it was possible for the planets to move in space as they did.

Background: In his book *On the Revolutions of the Heavenly Bodies,* Copernicus included a set of planetary tables. The tables, however, were based on insufficient and inaccurate observations. Until more complete and accurate observations of the heavenly bodies were available, Copernicus' theory could not be proven.

Tycho Brahe, shown on the far left of this page, provided these important observations, although he himself did not hold with the Copernican theory. Tycho was one of the greatest observational astronomers who ever lived, and he accomplished his work before the telescope had been invented.

In 1599, Johann Kepler became astronomical assistant to Tycho. Kepler tried to reduce the observed motion of the planet Mars to a rule and found that Mars's orbit was an ellipse. This Kepler later showed to hold also for the orbits of the other planets, including the earth. His discovery has come to be known as Kepler's First Law of Planetary Motion. He found that a planet did not move at the same speed at all points of its orbit; it moved in a more complicated manner, which he expressed in his Second Law. Some years later he discovered a Third Law of Planetary Motion—a simple arithmetical rule connecting the

size of a planet's orbit with the time taken by the planet to go once around it.

Galileo used the telescope to make discoveries that had an important bearing on the controversy between the old and the new systems of the world. He was the foremost exponent of the Copernican theory in his generation.

TEACHING SUGGESTIONS
(p. 158)

Background: The answers to *Using What You Have Learned* are:

1. The planets always move in an arc that contains the moon and the sun. Generally, only Venus, Mars, and Jupiter are visible to the eye, and they can best be found by visually tracing the path that the moon takes in its passage through the sky.

2. Mercury cannot be seen very well because it is very close to the sun and rises and sets with the sun. The light of the sun usually obscures it.

4. The diagrams are self-explanatory. Whether it is a morning star or an evening star depends on the relative positions of the sun, the earth, and Venus and on the direction of the earth's spin—eastward.

5. Because the earth is between the observer and the planet.

Using What You Have Learned

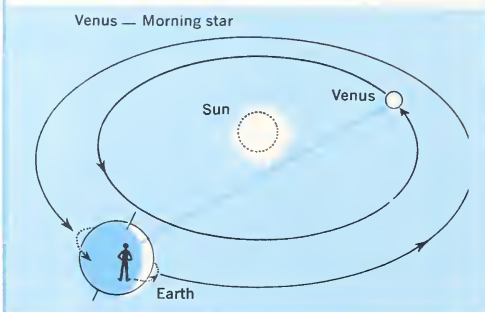
1. Check your local paper to find out which planets can be seen in the night sky this month. Look for them. Notice in which part of the sky you see them. Is each planet always found in the same position in the sky? Why? Keep records and compare the planets' positions with their positions next month.

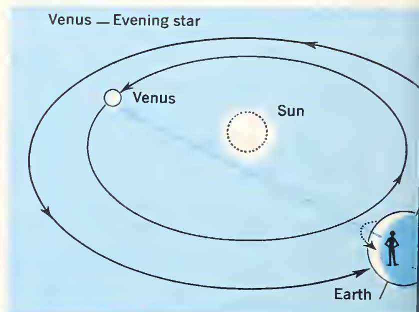
2. Can Mercury be seen as easily as Venus, Mars, and Jupiter? Why?

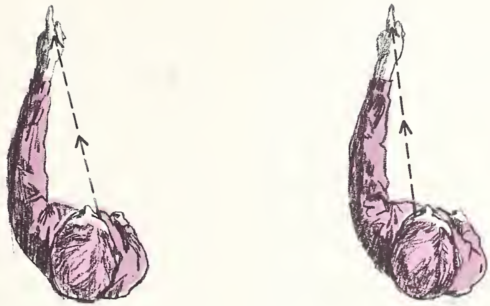
3. Prepare a special report on the life of Copernicus. Include such items as his nationality, where he went to school, what he studied, and reasons that might have led him to invent a new theory.

4. Sometimes we see Venus as a morning star, just before sunrise. At other times it is the evening star, seen just after sunset. Use the diagrams below to explain why Venus is sometimes a morning star and sometimes an evening star.

5. Why is it never possible to see Venus at midnight? Use the diagrams below to help you answer this question.







Locating Things in Space

Hold out one finger at arm's length. Look at it with one eye. Now, holding your finger still, shut the eye that was open and open the eye that was closed. What do you notice about your finger?

Now try this. Have a classmate hold a yardstick about three yards in front of you. Notice what you see directly behind the yardstick. Now take a big step sideward while your classmate holds the yardstick in the same place. Look at the yardstick again. What do you see directly behind it? Although the yardstick has not moved, it *seems* to have moved because you looked at it from two different places.

In the first activity, why did your forefinger seem to move against the background? It seemed to move because you looked at it from two different positions, the positions of each of your eyes. This apparent shift in position of an object when viewed from two different locations is called **parallax** (PAR-uh-lakss).

You can observe parallax in your classroom. Stand a book on your desk. Look at some nearby object from one edge of the book. Now look at the object from the opposite edge. Notice how the object seems to move against its background.

Now that you know about parallax, you realize that you have noticed it all your life. Can you think of how parallax has been useful to you, even though you may not have been aware of its usefulness before?

TEACHING SUGGESTIONS
(p. 159)

LESSON: What is parallax?

Background: The next several pages develop an understanding of the meaning of parallax. These pages contain many activities and, in fact, can be taught almost exclusively by having the pupils do the exercises and demonstrations, with just enough classroom discussion to be sure they understand the meaning of their work. This page attempts to define parallax by means of the simple demonstration given in the text.

Learnings to Be Developed:

When an object is viewed from two slightly different viewpoints, it appears to shift against the background of more distant objects. We call this phenomenon parallax.

Parallax makes it possible to estimate distance.

Developing the Lesson: The main portion of the time should be devoted to having the pupils attempt the activity. You can introduce the subject by saying that they will learn a method of measuring objects that are very great distances away, and which has proved very important in astronomy because it helped astronomers make up their minds between the Ptolemaic and Copernican theories. (It provided experimental proof, which had been lacking.)

TEACHING SUGGESTIONS
(pp. 160–161)

● LESSON: How is parallax related to the Copernican model of the solar system?

Background: The text is self-sufficient here, and very little exposition will be needed. These two pages can serve as an introduction to the experiment on page 162 and to the discussion on page 163. It might be mentioned here that even though parallax among the stars was not measured until the 19th century, the researches of Kepler into the motions of the planets and Newton's work on motion and gravity, which was based on Kepler's research, convinced all scientists that the planets of the solar system revolved around the sun and not the earth. The fact that parallax could not be measured was therefore rather academic, so far as proving or disproving either theory was concerned. The finding of the distances to the stars became chiefly of astronomic interest. The biography of Bessel on page 24 recounts briefly the story of the discovery of parallax in a star.

Learnings to Be Developed: Measurable parallax of a nearby star would constitute a proof of the Copernican theory.

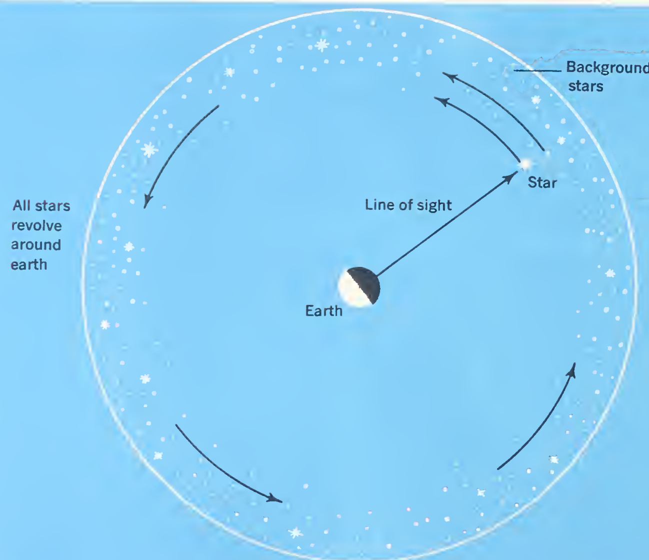
Copernicus and Parallax

Let us consider again the two models of the solar system. In the picture is an earth-centered model. You will recall that in this model the earth does not move. Imagine that you are on this earth and that you have selected a star to look at. In this model the entire sphere of stars goes around the earth. Should the background for any star ever change?

If the earth were at the center of everything, and if all objects in the sky went around the earth, then you would notice no parallax among the stars. Being on the earth would be like being at the center of a huge bicycle wheel. The wheel might turn, but things that were close to the center would not seem to move against the background of things farther away.

In the earth-centered model, near stars would not change position against distant stars.

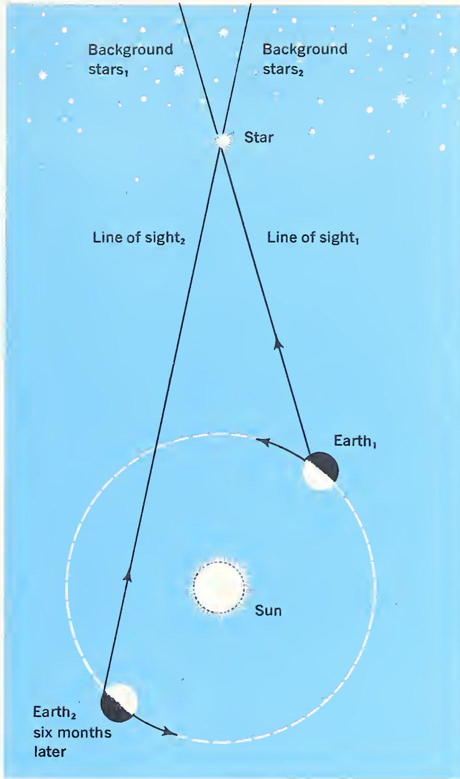
But what can we expect in the sun-centered model? Should near stars seem to shift position according to Copernicus' theory?



In the diagram on the right, the earth travels around the sun. You can see a line from the earth to a near star. Following the line you see the background against which this star appears. What is the position of the earth six months later? At that time the earth has traveled halfway in its orbit around the sun. It is at the bottom of this diagram. Now you want to look at the same star. The second line shows where you would expect to see this star from the opposite point on the earth's orbit. Because of parallax, you would expect to see the star against a different background. Does this happen?

The parallax test was put to the Copernican model. Astronomers said that if the earth moved around the sun, parallax would appear when you observed a close star six months apart. If there were no parallax, then the earth must be standing still. However, careful observations of nearby stars showed *no* parallax. For this reason, many great astronomers rejected Copernicus' theory.

Parallax for a nearby star was not detected for nearly three hundred years after Copernicus' death. The stars are very far away, much farther away than Copernicus or other astronomers of his time imagined. Because of their great distances from the earth, it is difficult



to measure parallax. Let us now find out the relationship between parallax and distance. You will do an experiment to find out. After you finish this experiment, see if you can think of another experiment to help you to find out the relationship between parallax and distance.

Developing the Lesson: Treat these two pages as an introduction to the experiment on page 162. You can have the pupils do the following activity to illustrate the discussion.

Have a pupil turn in a circle while remaining in one spot. He can turn slowly. As he turns he should try to see if objects close to him move relative to farther objects. They won't. This turning represents the motion of the earth if it were the center of the solar system—parallax cannot be seen. Then have the same pupil walk in a circle a few feet in diameter. He should again notice whether close objects seem to shift in position relative to more distant objects. Now they will. This walking in a circle represents the motion of the earth around the sun.

Follow-Up: This kind of behavior should be familiar to all the pupils from riding in automobiles, buses, or trains. If they look out of the side windows, closer objects flash by, while the more distant objects move at a speed proportional to their distance from the observer.

TEACHING SUGGESTIONS
(pp. 162–163)

LESSON: How does the parallax of an object change as the distance of an observer from the object increases?

Background: The purpose of this experiment is to show that the amount of parallax is reduced as the distance to the object increases. As many pupils as possible should try the experiment. The procedure should be self-evident. If you would like to conduct an experiment that is more quantitative and that would give the pupils an opportunity to compare measurements with greater accuracy, you can construct a sighting bar out of wood, in which are set two nails about 6 inches apart. The pencil can be fixed in position about 5 feet in front of a yardstick or the ruled lines on the chalkboard. The pupils can then measure with this sighting device in the same manner as they did with their eyes and with the pencil. The sighting device should be on a tripod or some other support to ensure steadiness. What the pupils are actually measuring, of course, are angles, but since they have not as yet studied trigonometry, the distances between ruled lines are equally effective.

EXPERIMENT

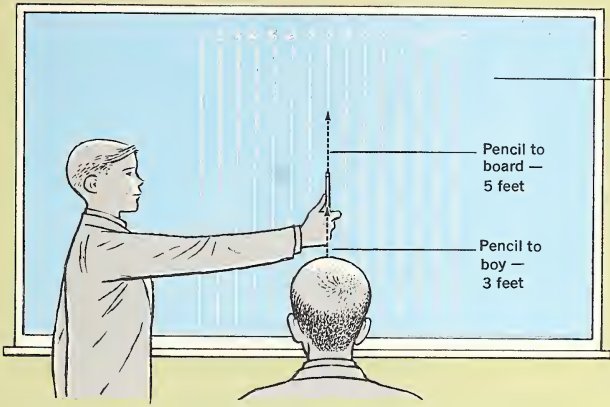
What Is the Relationship Between Parallax and the Distance to an Object?

What You Will Need

chalkboard pencil yardstick

How You Can Find Out

1. Make a series of about fifteen vertical lines about one inch apart across the chalkboard. Number each line as shown in the drawing. Have a classmate hold a pencil about five feet in front of the chalkboard. During the activity neither your friend nor his pencil must move.
2. Now stand about three feet from the pencil looking toward the lines on the chalkboard.
3. Look at the pencil first with one eye, then with the other.
4. Notice the parallax. Measure it by noting against which line the pencil appears when you view it with one eye. Then note against which line it appears when you view it with the other eye. Perhaps it appears near line 13 with your right eye and near line 8 with your left. For purposes of this activity, call this measurement a parallax of 5 (13 − 8 = 5). Make a record of the actual parallax you get at three feet from the pencil.
5. Now step back three feet to put yourself six feet from the pencil. Be sure your friend does not move.
6. Repeat the observation. Look at the pencil first with one eye, then with the other.
7. Make a record of this parallax. Remember that this observation is made six feet from the pencil.
8. Now step back three more feet. You are now nine feet from the pencil. Record the parallax measurement.
9. Step back another three feet. Record the new parallax.
10. Now try to answer the questions on the next page.



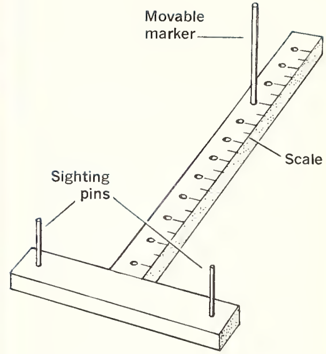
Questions to Think About

1. Examine your results for all the distances. What do you notice about your parallax measurements as you move farther away from the pencil?
2. What do you think you would observe if you moved about 100 feet from the pencil, looking at it first with one eye, and then with the other? Do you think you would detect any parallax?

Even the nearest star is so far away that its apparent shift of position against the background of the farther stars is very slight.

The slight parallax of a near star was not measured until the 1830's. In 1838, the German astronomer Friedrich Bessel, whom you read about on pages 24 and 25, measured the parallax of the star called 61 Cygni. You can review how he did this by rereading the Pathfinders in Science section on pages 24 and 25. By the time he lived, finer instruments had been developed than those available at the time of Copernicus, and so the proof of Copernicus' theory by using parallax became possible. A star does shift its position against its background when viewed from the earth. Copernicus' idea that the earth was moving explained the shift.

In the next part of this unit, you will find out how parallax measurements can be used to find actual distances.



Learnings to Be Developed: As the distance from an observer to an object increases, the amount of parallax decreases.

Developing the Lesson: Before the experiment is conducted, tell the pupils they are going to try an experiment similar to the one that astronomers tried to discover whether the stars showed parallax.

Following the experiment, you can discuss the conclusions that the pupils reached. You can conclude by mentioning Bessel's measurements of the parallax of 61 Cygni. He had to wait 6 months between each set of measurements and the next, until the base line—the earth's orbit—was at its maximum extent, and he took many readings in order to obtain an accurate average. The fineness of his measurements can be gauged by the fact that he was, in effect, measuring the thickness of a human hair at a distance of 10 miles.

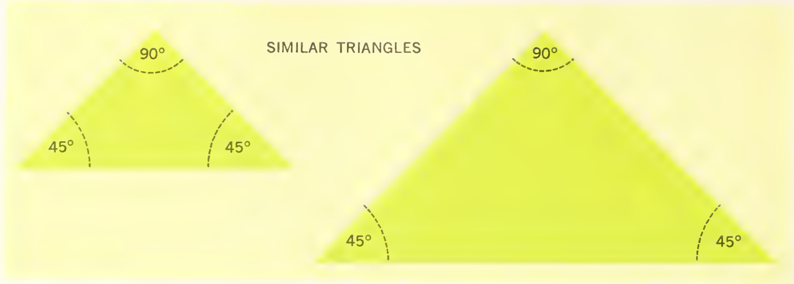
TEACHING SUGGESTIONS
(pp. 164–167)

LESSON: How are triangles used to measure distances?

Background: The pupils have discussed parallax and have learned, in general, how astronomers use triangles to find distances. This lesson carries their knowledge further by giving the pupils experience in using triangles and in learning to measure distances using similar triangles. Some of the pupils may need help in learning how to read and use a protractor. Have them draw angles of different sizes to gain experience before proceeding with this unit. Be sure they know how to read their protractors correctly. Instead of using plain white paper on which to draw the 30°-60°-90° triangles, they can use graph paper that is marked off in 1/4-inch squares. Then the size of the triangles becomes more certain.

Having completed their triangles, they can discover by measuring the sides with a ruler that the sides of the larger triangle are twice as long as the sides of the smaller triangle.

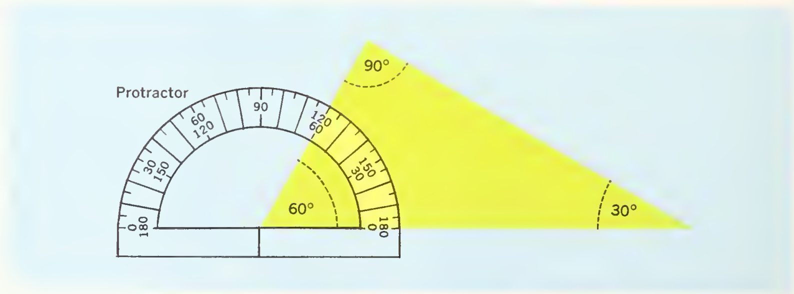
Learnings to Be Developed: Triangles can be used to measure distances by using simple proportions.



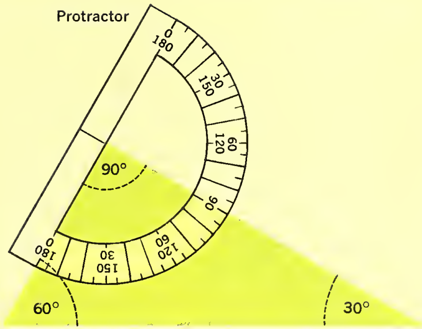
Using Triangles to Measure Distances

You can use parallax to measure how far away objects are. But first you must know a few facts about **triangles.** A triangle is a closed figure with three straight sides and three angles. In the drawing above are two *similar* triangles. Although the sides have different lengths, the triangles have the same shape. Their angles are equal. The size of an angle is measured with a **protractor,** as you see in the drawing below.

Draw two triangles, each on a separate sheet of paper. Start by making the bottom, or base, of one triangle exactly 2 inches long. Make the base of the other triangle exactly 4 inches long. Make an angle of 60° at the left end of each base. Make a 30° angle at the right end of each base. Extend the lines on each sheet of paper until you have made triangles.



[illegible] the [illegible] as the [illegible] work in class. Proceed [illegible] with the directions, making sure that each step is understood before



You know certain facts about these triangles that you have drawn. Each triangle has one angle of 30°. Each triangle has one angle of 60°. The base of one triangle is 2 inches. The base of the other triangle is 4 inches. What else can you find out about these triangles?

Carefully measure the third angle on each triangle with a protractor. These angles should both be 90°. In every triangle the sum of the measures of the angles is 180°. This is true no matter what its shape or size. In the triangles you have drawn, $60° + 30° + 90° = 180°$.

What else can you find out about these triangles? How does the length of one of the sides of one of the triangles compare with the length of the corresponding side of the other triangle? You know that the base of one is exactly twice as long as the base of the other. What about the other sides? Measure and compare the lengths of the other sides of the triangles. What do you discover?

The facts that you have discovered about similar triangles can be used to measure distances. Imagine that a surveyor wants to measure the distance across a deep gorge. He cannot stretch a tape measure across the gorge without falling in.

What he needs is a triangle similar to the one shown on page 166. First

...ing on to the next. Careful supervision will develop ability to read this type of mate-rial which pupils will increasingly encounter in higher grades.

Developing the Lesson: Follow the procedure given in the text to develop the lesson. This lesson can be introduced by referring back to the knowledge about distance and parallax gained from the experiment on page 162. Point out now that merely knowing that the parallax of distance objects is less than that of near objects is not enough. Scientists want accurate measurements. What the pupils will learn in this activity is one way that scientists measure distances accurately.

As an additional method of learning the properties of triangles, the pupils can draw triangles of different sizes on a sheet of graph paper. They will each need an inexpensive 30°-60°-90° triangle for this activity. Using the triangles they can quickly see, by using base lines of different lengths, that the sides change in proportion to the length of the base. The advantage of using graph paper is that they can easily count off the height of the triangles to check that the proportion of base to height remains constant. As for the measuring of distances across rivers and gorges, perhaps it would be simpler and more understandable to the pupils if you began by using right triangles rather than triangles consisting of odd angles. It would be best to go through an example on

the chalkboard that the pupils can follow at their desks before having them try a problem by themselves. When they have grasped the idea, then you can have them cut out a 30°-70°-80° triangle, using their protractors, and attempt to do the problem given on page 167 at their desks.

he finds two points (A and B) to form a *base line*. He measures the actual length of the base line. Suppose it is 100 yards long. Then he measures the angle at A by sighting a tree on the opposite side of the gorge. Next he measures the angle at B by sighting the same tree. Suppose these angles are 70° and 80°.

On a sheet of paper he could make a similar triangle which is really a scale drawing of the imaginary triangle formed by the base line of 100 yards and the two angles. For his scale drawing he makes his base line 10 inches long. Ten inches represent 100 yards, so 1 inch represents 10 yards. Then he draws the 70° and the 80° angles on his scale drawing to complete the similar triangle.

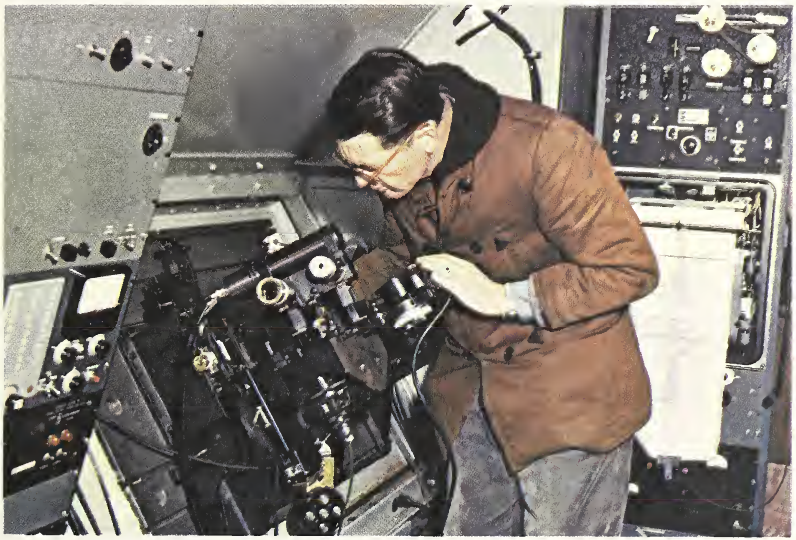
Perhaps you can make the scale drawing for this example on the chalkboard of your classroom. Let one inch represent 10 yards, so that 10 inches represent 100 yards. Then draw angles of 70° and 80° and complete the triangle. Now measure the sides. By multiplying the lengths of the sides by

10, you can find the distance across the gorge in yards.

Now use the scale drawing to answer these questions: How far is it from A to the tree? How far is it from B to the tree? What is the shortest distance across the gorge? What measurement must you make on your scale drawing to find this distance?

Astronomers use a method similar to this one for measuring distances in space. First they need a long base line. Then they measure the angle from each end of the base line to the planet whose distance from the earth they want to learn. They might then draw a similar triangle, but it is not necessary. Once they know three facts about the huge triangle—the length of the base line and the sizes of two angles—they can get the rest of the information about the triangle from charts. The basic method, however, is just like the surveyor's method.

Astronomers use complicated instruments to measure distances to the stars. Look up *spectroscope* in a high-school science book. How do astronomers use the spectroscope?



Background: The answers to the questions on this page are as follows: If 1 inch represents 10 yards, then it is approximately $22\frac{1}{4}$ inches from A to the tree; it is approximately 21 inches from B to the tree. The shortest distance across the gorge is about $20\frac{3}{4}$ inches. The figures must be multiplied by 10 and the units converted to yards in order to translate the scale drawing to the "actual" situation.

TEACHING SUGGESTIONS
(pp. 168–170)

Background: The answers to *Using What You Have Learned* are:

1. The parallax becomes greater as the base line becomes longer.

4. Scientists can work from trigonometry tables. To use these tables, they must know the length of the base line and the sizes of two angles. This information is sufficient for them to calculate the remaining dimensions of the triangle.

If astronomers use the diameter of the earth as a base line for making observations, they are using a base line of about 8,000 miles. If they use the diameter of the earth's orbit about the sun, the base line is about 186,000,000 miles.

Using the information given in this problem, the distance between the origin and the point where the distance is 1/2 inch should be about 14 1/3 inches.

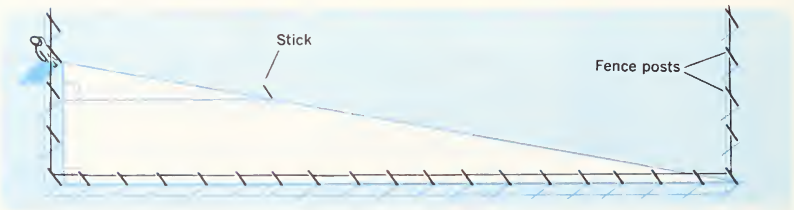
ADDITIONAL ACTIVITIES:

Have the pupils determine distances between objects in the classroom using the method of similar triangles. The longer the base line, the more accurate their measurements will be. Very accurate triangles of any size can

Using What You Have Learned

1. Find the relationship between parallax and the length of the base line. In the activity on page 162, you found out that parallax gets smaller as the distance to the object increases. Now plan an activity to discover how parallax changes if the base line gets longer. For this activity, keep the distance to the object the same.

2. Measure the distance to an object in the schoolyard using the method of similar triangles. (Perhaps you can find the length of the schoolyard by measuring the distance from one end to a post at the other end.)

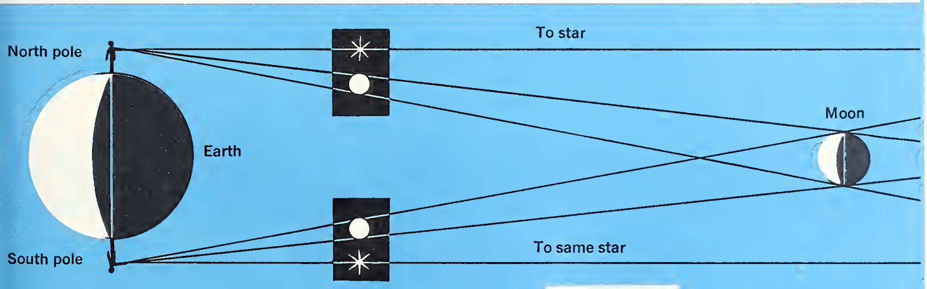


3. Check your results in activity **2** by measuring the distance to the object directly. That is, measure the distance by pacing it off or using a yardstick. How does the result compare with the answer you got in activity **2**? What are some places where you might have made errors in activity **2**?

4. On page 164, you read about similar triangles. You also read that scientists need not actually draw similar triangles to get the information they need. When astronomers use the parallax method, they need to find only certain facts. Then they can figure out the others without actually drawing similar triangles. What measurements does an astronomer need to make to use the parallax method?

The distance from the earth to the moon was first found by using the parallax method. The main difficulty in finding this distance lies in finding a base line that is long enough. A base line of 100 yards, or even one of 100 miles, is too short, because the parallax angle is not large enough to be measured. To find the distance to the moon, a base line that is thousands of miles long is needed. Before you look below, can you tell what might serve as such a base line?

a. Now suppose we could use the diameter of the earth for a base line. To do this, you would need to place yourself at the North Pole and a friend at the South Pole. First, you both would sight at the same star. Even the nearest star is so far away that you would both be pointing in the same direction. (The actual difference in direction is so small that we could not measure it.) The picture shows you and your friend looking at the star with telescopes so that the angle between the lines of sight and the earth's axis is 90°. Then, at a certain time, you both would sight at the moon. Now you no longer would point in the same direction as your friend. You each would measure the angle between the direction to the moon and the direction to the star. You each would find that the angle is about 1°.



be made by obtaining a length of string or twine and marking off lengths in the proportion of 3 to 4 to 5. When the ends of the string are tied together and held taut at the marks, a 30-60°-90° triangle is formed. Using this triangle made of string, the pupils can very quickly "survey" the distances between objects in the room.

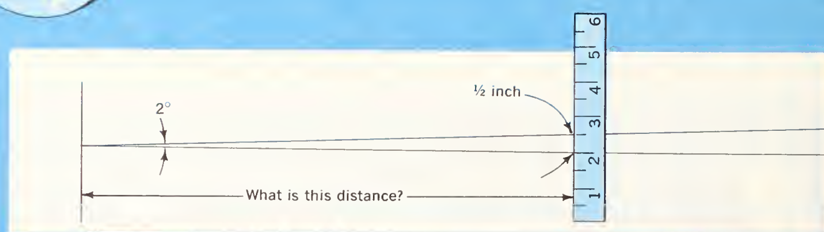
Another interesting way in which the pupils can learn the properties of similar triangles is to have them do a bit of simple map-making. Have them obtain a large corrugated-cardboard box, the larger the better. The box should be rigid, which means that any open sides must be closed and fastened down with paper tape.

Have them fasten a sheet of clean paper on one end of the box, and in the center of the sheet of paper they can stick a small pin. The box can then be carried out to the playground or another open space. Set the box down, making sure it is reasonably level. Have the pupils sight along the top of the box so that the pin is lined up with various prominent objects in the distance—a flag-pole, say, a tree, the corner of a building, and so on. All that need be done is have the pupils draw straight lines extending from the pin in the direction of the objects sighted.

The box can then be moved some distance away. Another line must be drawn on the sheet to represent both the distance the box was moved and the direction it was moved. Stick another pin into the cardboard to represent this second position. Now, from this new base point, the pupils can sight again the objects already sighted from the first position. The intersection of the lines drawn from the first and second positions will result in a map of the local area, showing both the relative distances and angles of the objects from each other.

b. Using a protractor, draw an angle of 2° on a long sheet of paper. (You will need one about twenty inches long. You can tape two pieces together if you do not have one piece long enough.) Draw the angle as carefully as you can and make the lines very straight. Then measure the distance between the lines and find the place where they are ½ inch apart.

The diameter of the earth is about 8,000 miles, so if this ½ inch represents 8,000 miles, then 1 inch represents 16,000 miles. Now measure the distance from where the lines are ½ inch apart to where they meet. From this measurement, what do you get for the distance from the earth to the moon?



Finding the Sizes of Objects in Space

Similar triangles can also be used to measure the sizes of planets, the sun, and the moon. By size, the astronomer means the distance across the planet, sun, or moon through its center, that is, the *diameter*.

You probably know that you cannot learn very much about the actual size of an object from the size it *seems* to be. Try this. Hold a penny between your eye and the classroom clock. Hold it just far enough away so the penny blocks your view of the entire face of the clock. In this position, the penny and clock *appear* to be the same size. But of course the diameter of the clock is much greater than the diameter of your penny.

Let us see if you can measure the diameter of the clock if you know how far away it is.

By using similar triangles, you can find the *size* of an object if you know *how far away* it is.

TEACHING SUGGESTIONS
(pp. 171–173)

LESSON: How can the sizes of distant objects be measured?

Background: By this time, the pupils should have learned how similar triangles can be used to measure unknown distances. This section shows how similar triangles are applied to the problems of astronomy. But before going on, you should be sure that the pupils really understand the principle of using similar triangles for measurements.

Learnings to Be Developed: Sizes may be measured by triangulation.

Developing the Lesson: Review briefly the lesson on pages 166-167 on how a surveyor measures an unknown length by the use of similar triangles. Be sure the pupils understand how, from a base line of known length and two angles of known size, an unknown distance can be found. Then ask the pupils how they would go about finding the length of the base line if the surveyor were standing on the opposite side of the gorge and knew only the distance to the base line. Note that the problem has simply been turned around. Now it is the angles and the distance (one side) that are known and the length of the baseline that is unknown. By asking the appro-

priate questions, you can lead them to recognize that all the surveyor need do is construct a small triangle on his side of the gorge, measure the side equivalent to the unknown base line, and then, by simple proportion, calculate how long the base line is. The experiment on this page should help make the idea clear to the pupils.

EXPERIMENT

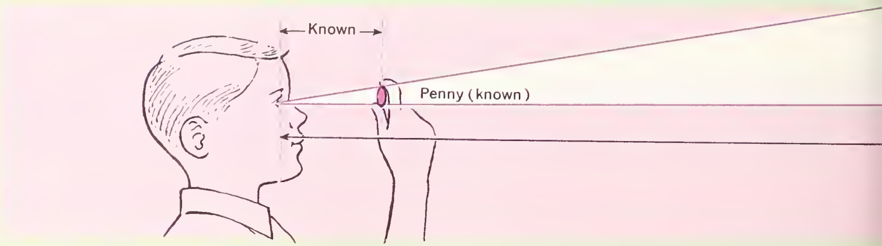
How Can You Find the Size of an Object by Using Similar Triangles?

What You Will Need

penny	yardstick or
classroom clock	tape measure

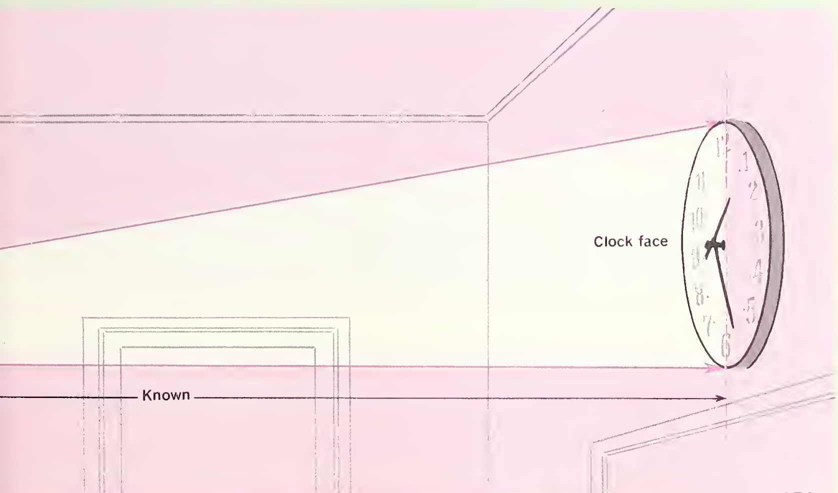
How You Can Find Out

1. Stand in a single spot for this activity. Measure the distance between this spot and the classroom clock with a yardstick or tape measure. If your classroom has no clock, cut out a circle about the same size as a clock and tack it on the bulletin board.
2. Hold a penny between the clock and your eye. Hold it at exactly the distance where the penny completely and fully blocks your view of the face of the clock, but no closer.
3. Have a classmate measure the distance between your eye and the center of the penny.
4. Carefully measure the diameter of the penny.
5. Notice that you have measured certain sides of similar triangles. One triangle is marked out by your eye and the opposite edges of the penny. The other triangle is outlined by your eye and the opposite edges of the clock. Notice also that these particular similar triangles share one angle, the one near your eye.
6. Now answer the questions on the next page.



Questions to Think About

1. Remember that if one side of a triangle is twice as long as the corresponding side of a similar triangle, the other sides of that triangle are twice as long as their corresponding sides, too. Look at the diagram again. You know two facts about the small triangle. You know the distance of one side (the distance between your eye and the penny). You also know the distance across the end (the diameter of the penny). You know one corresponding side of the big triangle—the distance between your eye and the clock. *Exactly* how many times longer is the distance to the clock than the distance to the penny? Figure it out.
2. Your answer tells you how many times bigger the clock is than the penny. What is the diameter of the clock?
3. Can you think of other ways in which you can find the size of an object by using similar triangles?



When answering the *Questions to Think About* on this page, the pupils should divide the distance between the eye and the clock by the distance between the eye and the penny and multiply the answer by the diameter of the penny to find the diameter of the clock. The essential thing to remember is that only simple proportions are involved:

$$\frac{\text{diameter of clock}}{\text{distance of clock}} = \frac{\text{diameter of penny}}{\text{distance of penny}}$$

or,

$$\text{diameter of clock} = \frac{\text{diameter of penny} \times \text{distance of clock}}{\text{distance of penny}}$$

Follow-Up: After the pupils have completed the experiment, have a pupil explain at the chalkboard, with the help of a diagram, exactly why he got the result he did. Since it is unlikely that all the pupils got similar answers, have the class discuss their answers. In this way, those who have not understood the method or who have committed some gross error will be recognized, and you can help them with their mistakes.

TEACHING SUGGESTIONS
(p. 174)

LESSON: How can you measure the size of the moon?

Background: The activity is precisely the same as the experiment on page 173, except that the principle involved is now being used to show how actual astronomical measurements are made. Do not overstress precision in the pupils' measurements. The important thing is that they understand the general method. For this activity, the diameter of the moon is assumed to be 2,000 miles.

Learnings to Be Developed: The technique of similar triangles can be used for actual astronomical measurements.

Developing the Lesson: Divide the class into groups and have each group make its own measurements and its own report in class.

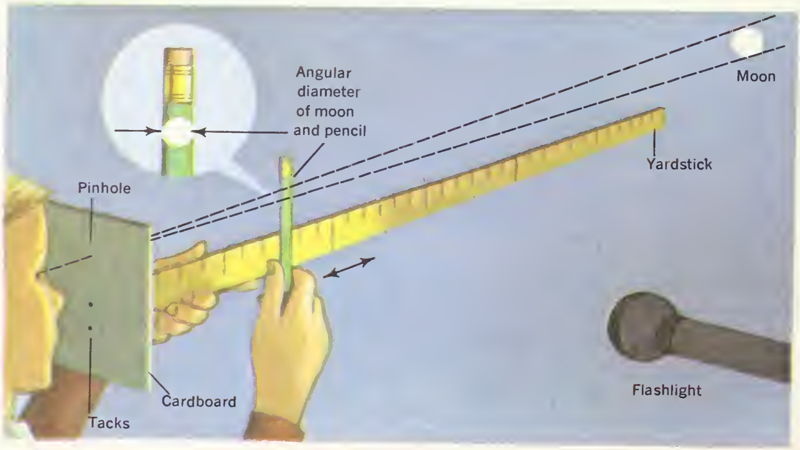
Background: The aim of the activities described here is to discover the distance of an object if you know its size but don't know its distance. A car, say, is 10 feet long. It is parked a considerable distance away, and the object is to discover what this distance is. By measuring with a protractor,

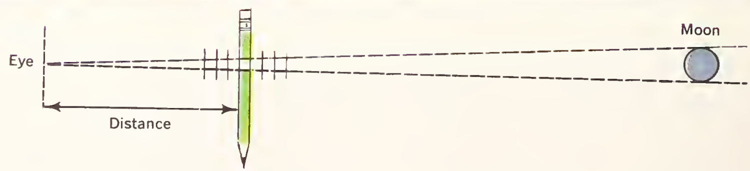
You can use the same experimental method to find the size of the moon.

Here is a diagram of how you can use a pencil, a yardstick, and a piece of cardboard to measure the size of the moon. This activity is best done on a dark night when there is a full moon. Tack a sheet of cardboard to the end of a yardstick. Put a small slit in the cardboard. Point the yardstick at the moon as you see in the diagram.

Now move the pencil along the yardstick until it *just* blocks your view of the moon. How far is the pencil from your eye? Next measure the diameter of the pencil.

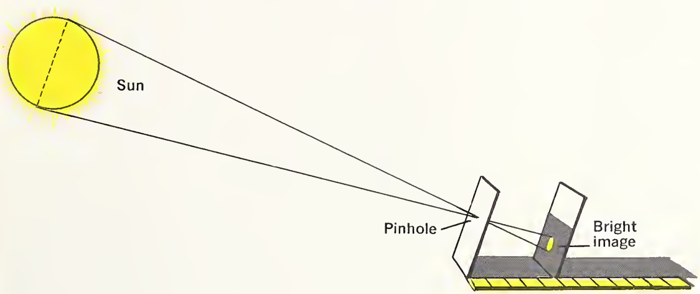
You now have three facts that correspond to the three facts for figuring the size of the classroom clock. You know the distance to the moon (240,000 miles), the distance to the pencil, and the diameter of the pencil. What is the diameter of the moon?





Using What You Have Learned

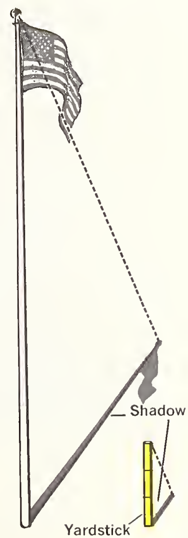
1. Practice the method of using similar triangles to find sizes. Cut out circles. See how accurately you can figure out their diameters.



2. You can use similar triangles to find the size of the sun. But since the sun is too bright to look at directly, the method is slightly different from the one for finding the size of the moon. You can look at the sun's image instead of the sun itself. Here you see a diagram of the method. Be sure the pinhole is just the right size to form a bright image. Be sure also that both pieces of cardboard face the sun squarely.

Can you find the similar triangles? Measure the distance between the pinhole and the sun's image. Measure the diameter of the sun's image. The sun is about 93,000,000 miles away. How big is it?

3. Look for the similar triangles in this activity. If you find them, you can figure out a method for getting the height of a flagpole, a tree, or a building without climbing to the top. What is the method? Use the diagram for clues.



it is found that the car subtends an angle of 5 degrees. How far away is the car?

Cut a strip of cardboard exactly 1 inch long. Move the strip along a yardstick until it also subtends an angle of 5 degrees. Measure its distance from the end of the yardstick. Since 1 inch is 1/120 of 10 feet, the distance away must be 120 times the distance measured.

(p. 175)

Background: When pupils do problem 2, tell them that the method used to determine the diameter of the moon can be used to determine the diameter of the sun. They should know that in an eclipse of the sun, the moon just blocks the disk of the sun. The apparent diameters of the sun and the moon are the same. Knowing this fact, and knowing also that the moon is 240,000 miles away, that the sun is 93,000,000 miles away, and that the diameter of the moon is 2,000 miles, have pupils calculate the diameter of the sun (775,000 miles). If necessary to clarify the situation and to indicate the dimensions, illustrate an eclipse on the chalkboard.

TEACHING SUGGESTIONS
(pp. 176–177)

LESSON: How is the speed of light used to calculate astronomical distances?

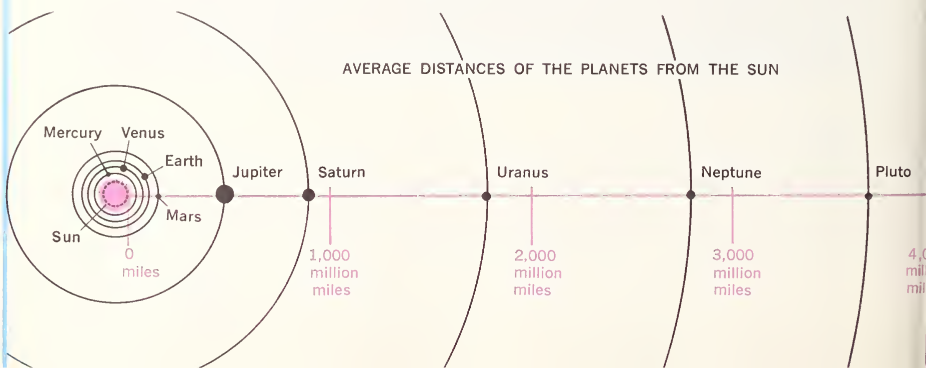
Background: It would be best to introduce the pupils to the meanings of the astronomical terms used in this section. The other methods that astronomers have used to develop a picture of the universe have included the use of the telescope, to which has been attached various accessories such as spectrographs, photometers, and cameras. The two main branches of astronomy are positional, or observational, astronomy—which seeks to determine the positions and numbers of the planets, stars, and other heavenly bodies—and astrophysics, which makes use of the instruments mentioned above to analyze the composition of the stars. Another point that can be made here is that the geometric methods to which the pupils have been introduced provide the basic measure of the universe. The mean distance from the earth to the sun is one astronomical unit, and it is used by astronomers much as the meter is used as a standard on earth. Scientists have used this distance to measure the distances of other objects in the universe

Viewing the Universe

By using the methods described in this unit—and many other methods as well—astronomers have arrived at a picture of the universe that Ptolemy would hardly recognize. For one thing, distances are much greater than he ever imagined. If you could travel at 1,000 miles per hour toward the *nearest* star other than the sun, it would take you about 3 million years to get there. In fact, distances beyond our solar system are so great they are measured in **light-years**. One light-year is the distance traveled by light in one year. The speed of light is about 186,000 miles per second. To find out how far light travels in a year, you must multiply 186,000 miles by the number of seconds in a year! The answer is about 6 million million (6 trillion) miles—which written out looks like this: 6,000,000,000,000. The nearest star is about 4½ light-years away.

Ptolemy would even be surprised by distances within the solar system and the small sizes of the planets compared with these distances. Imagine a model of the solar system. Imagine on this model that the earth is 1 inch in diameter. (On this scale, 1 inch equals about 8,000 miles.) Then the sun would be about 3 *yards* in diameter. The earth would be about 320 yards from the sun. Jupiter would be about 1½ miles from the sun.

Of course Ptolemy would have been most surprised by the fact that the earth is not at the center of everything. The sun is at the center of the system. Nine planets go around the sun in paths that are almost circles. Many of the planets have moons: the earth has one, Mars has two, and Jupiter has twelve. In the table on page 177, you will find some more facts about the planets.



Sizes of the Planets and Distances from the Sun

Planet	Distance from the Sun (miles)	Diameter of the Planet (miles)
MERCURY	36,000,000	2,900
VENUS	67,000,000	7,600
EARTH	93,000,000	7,900
MARS	142,000,000	4,200
JUPITER	483,000,000	87,000
SATURN	886,000,000	72,000
URANUS	1,783,000,000	29,000
NEPTUNE	2,794,000,000	28,000
PLUTO	3,670,000,000	3,600

Pluto is about $37\frac{1}{2}$ light-days distant: compare with the distance of the nearest star

and to calculate the speed of light, which has given them a method of measuring the distances of the stars.

Learnings to Be Developed:

Astronomical distances are calculated in light-years.

Many facts about the sun and its nine planets have been found by indirect methods of measurement.

Developing the Lesson: The pupils have probably heard a great deal about light-years, and it should prove interesting to calculate distances in this measure. Given the fact that light travels at the rate of 186,000 miles per second, have them convert this figure into light-seconds, light-minutes, light-hours, light-days, and then light-years.

1 light-second = 186,000 miles
1 light-minute = 11,160,000 miles
1 light-hour = 669,600,000 miles
1-light-day = 16,070,400,000 miles
1 light-year = 5,865,696,000,000 miles

The table on page 177 gives the distances of the planets from the sun in miles. It should prove interesting to discover that the earth is about $8\frac{1}{3}$ light-minutes distant from the sun.

TEACHING SUGGESTIONS
(pp. 178–179)

● **LESSON:** What determines the velocity at which the planets travel around the sun?

Background: The material on these pages reviews gravitation — the closer a planet is to the sun, the greater the force of the gravitational attraction, and the faster must the planet travel to avoid falling into the sun. How can we calculate the velocity of the different planets? The circumference of a circle is given by the formula

$$C = 2\pi r$$

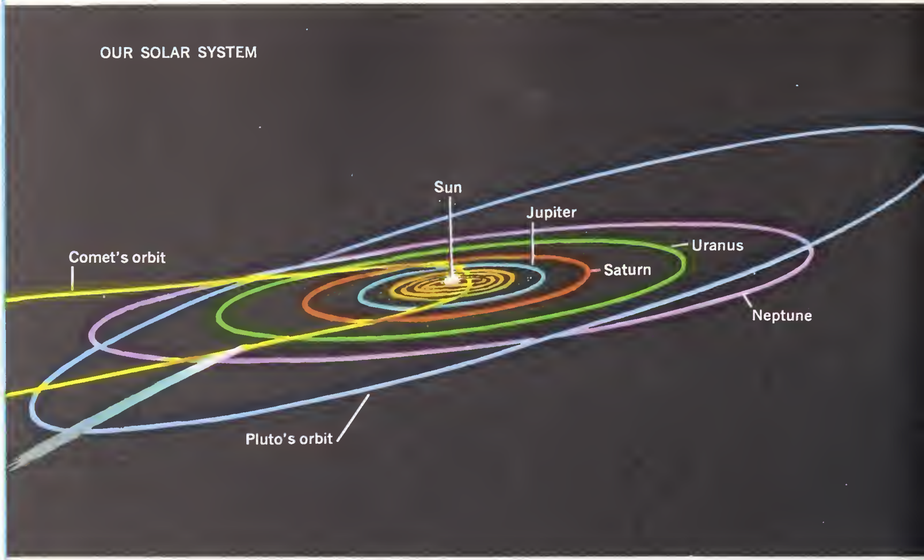
On page 177 there is a table giving the distances of the planets from the sun. These distances are obviously the radii of the planets' orbits also. Mercury's orbit has a radius of 36,000,000 miles. Inserting the proper figures in the formula, we get for Mercury:

$$C = 2 \times 3.14 \times 36{,}000{,}000 \text{ miles}$$
$$= 1{,}055{,}040{,}000 \text{ miles}$$

From the table on page 179 we learn that it takes 88 days for Mercury to circle the sun.

$$\frac{1{,}055{,}040{,}000 \text{ miles}}{88 \text{ days}} = \begin{matrix}11{,}982{,}272\\ \text{mi. per day}\end{matrix}$$

If we follow the same procedure for the other planets, we discover that the earth travels about 797,000 miles per day, and Nep-



If you could view the solar system from afar, you would see that it is very flat. Its shape is something like a phonograph record—a disk. Only Pluto and the comets move out of the disk.

Within the disk, you would see all the planets moving in the same direction around the sun—counterclockwise when viewed from the "top." But the planets do not all move at the same speed. Those closer to the sun move faster. For example, Mercury goes around the sun in 88 of our days. Its orbit is smaller than the earth's, and its speed is greater. The earth, whose orbit is greater and whose speed is less, orbits the sun in 365 of our days.

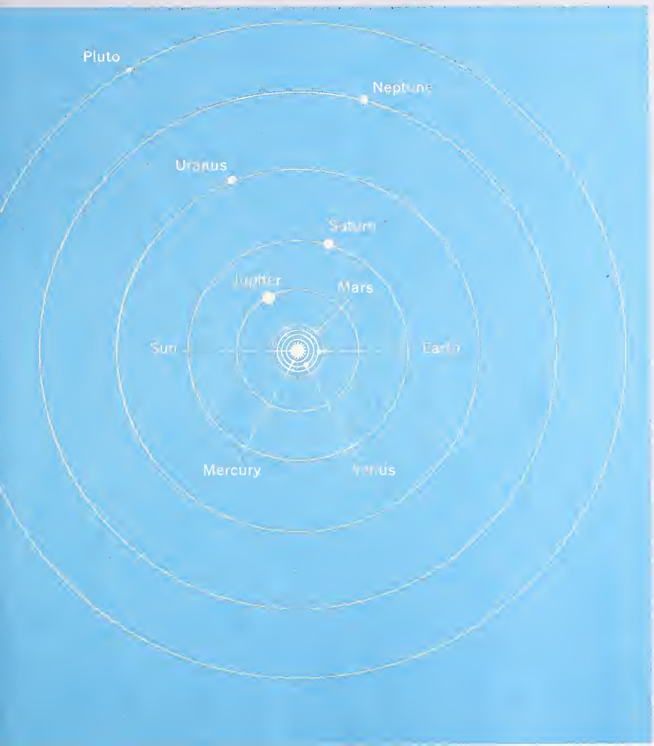
It takes Mars almost two of our years to go around the sun once. It takes Saturn close to 30 years. Neptune goes around in about 164 years.

As the earth moves around the sun, it travels about 291 million miles. It does this once each year, or in 365 days. How far does the earth travel

each day? The planet Mercury travels about 113 million miles as it goes around the sun in 88 days. How far does Mercury travel each day? How much faster does Mercury travel than the earth? As Neptune travels around the sun, it goes about 8,782 million miles in 59,860 days. How many miles does it travel each day? How does its speed compare with the speeds of the earth and Mercury?

Of course, most of what you would see if you could view the entire solar system would be space. The planets are tiny compared with the huge distances between them.

TIME IT TAKES PLANETS TO GO AROUND THE SUN



Pluto	248 years
Neptune	164 years
Uranus	84 years
Saturn	29 years
Jupiter	12 years
Mars	1 year and 241 days
Earth	365 days
Venus	215 days
Mercury	88 days

tune travels about 146,000 miles per day. Obviously, then, the farther a planet is from the sun, the slower it travels; the closer it is, the faster it travels.

Learnings to Be Developed:

A balance of forces exists in the solar system between the distances of the planets from the sun, their masses, and their gravitational attraction on each other.

This balance of forces results in a certain velocity that prevents the planets from falling into the sun and that maintains them in their orbits.

Developing the Lesson: Remind the class that on page 84 they learned that it required a velocity of 5 miles per second to place a space capsule in orbit. The space capsule must maintain this velocity to remain in its orbit. Then develop the information contained in the *Background* to show the pupils that the velocity needed to keep the planets in orbit around the sun depends on the same things needed to keep the space capsule in orbit—and these things are a balance between the gravitational attraction of the respective masses and their distances from each other. Conclude by working out the problem given in the *Background* section and have the pupils solve the same problem for the earth and for Neptune.

TEACHING SUGGESTIONS
(pp. 180–181)

Background: In 1931, Karl G. Jansky, an engineer working for the Bell Telephone Laboratories, was studying the causes of static in radio receivers. He discovered a new kind of static he couldn't account for and found that this static seemed to come from the center of the Milky Way. Little notice was taken of his discovery, however, except by an amateur radio enthusiast named Grote Reber. Reber constructed a parabolic receiver in 1937 with which he proceeded to map the sky. He found that the entire Milky Way emitted electromagnetic radiations in radio wavelengths, with the strongest radiations in the center of the Milky Way.

The present interest in radio astronomy, however, began after World War II, when English, Australian, and Dutch astronomers, in particular, constructed special receivers and began to study the radio signals in detail.

The parabolic receiver described in the text is one type of receiver used. Another type consists of two or more antennae that can be moved closer to or farther apart from each other and which act as an interferometer. By analogy with sound waves, if sounds of

A. C. Bernard Lovell

(1913–   ) England

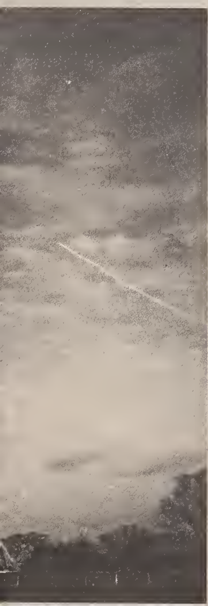
For hundreds of years astronomers have used telescopes to see into space. With their telescopes they have discovered new planets, stars, and comets. They have discovered what the stars are made of and how the stars are born and die.

But astronomers in this century were dissatisfied. Looking into space from the surface of the earth is like looking into a garden through a very dirty window. The earth's atmosphere acts as a filter, blocking off most of the starlight that reaches the earth. What astronomers wanted was a way to open the window.

There was a way. In the 1930's, scientists using sensitive radio equipment discovered by accident that they were receiving faint, mysterious noises in their radios. They discovered this noise came from outer space. Astronomers were certain that this noise was caused by the stars, in exactly the same way that a flash of lightning can cause static in an ordinary radio receiver. But they could not be positive about this until they could pinpoint exactly where in the universe the noise was coming from.

Unfortunately, they could not learn anything at first, because there was no way to focus these faint noises as they could focus starlight in their telescopes.

Bernard Lovell was an English scientist who was born the son of a poor postman in a small village. During World War II he helped design radar equipment. Lovell became interested in these noises from outer space. He knew that it would



be necessary to build a curved reflector like a radar antenna to focus these faint noises accurately. He convinced the British government that it would be worthwhile to build a reflector that was 250 feet in diameter (almost the size of a football field). The reflector would focus the faint noises into a specially designed radio receiver. Because the radio receiver was very sensitive, the scientists could focus the reflector very accurately. This *radio telescope* was built in the English countryside, near a place called Jodrell Bank.

The Jodrell Bank radio telescope has done all that Lovell hoped it would. He has discovered new kinds of stars that astronomers never knew existed. The radio telescope has also revealed a thin, cold hydrogen gas in space, which could not be seen with optical telescopes because it does not give off light. But the radio waves that this gas generates, like those from the stars we can hear but not see, pass through the interstellar dust and debris to be picked up on earth.

For his achievements, Bernard Lovell was knighted by Queen Elizabeth II.

almost identical frequencies are heard at the same time, one hears not the two separate tones but a beat that is the difference between the two frequencies. In the same way, by varying the distance between the two receivers, it is possible to strengthen the radio signal in such a way as to enable the astronomer to locate its position precisely in space.

The larger the receiving antenna, the more precisely will the antenna point out the source of the signal. Stationary antennae have been built on the ground that are several hundred feet long and that depend on the earth's motion through space to scan the sky.

What have radio telescopes discovered? That the entire Milky Way radiates signals of different wavelengths, that there are points in the sky (discrete radio stars) that radiate radio signals, and that the sun, distant galaxies, and even the planets Jupiter and Venus radiate signals. The chief causes of the signals are clouds of hydrogen gas, or other gaseous clouds, that interact with each other. As they do, the atoms of which they consist collide with each other, and this causes them to radiate electromagnetic energy in the frequencies of a radio wave band.

The radiations given off by neutral hydrogen atoms in the 21-centimeter band have been particularly valuable. These radiations have a very precise frequency, which enables astronomers to calculate their distance and the speed at which they are moving through the universe. From these calculations, astronomers are discovering new facts about the origin and composition of the universe.

TEACHING SUGGESTION
(pp. 182-186)

LESSON: How large is the universe?

Background: The enormity of the distances and sizes involved are completely outside anyone's experience, and one can only stand in awe. Reading these pages will help give the pupils some idea of the vastness of space and the smallness of the solar system in this scheme.

Learnings to Be Developed:

The pupils should acquire some feeling for the magnitude of the universe.

The sun is only one of billions of stars making up our galaxy.

There are billions of galaxies in the universe.

Galaxies

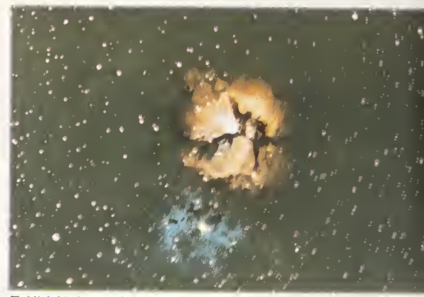
For about forty years, astronomers have known that our sun is one star in a large group of stars called a **galaxy.** A galaxy, like the solar system, is very flat and consists mostly of space.

Our galaxy, which is known as the Milky Way Galaxy, is relatively as flat as a half-dollar, although it is slightly bulged in the middle.

Distances between stars in a galaxy are difficult to imagine. Imagine that the sun is the size of a ping-pong ball. On this scale, the nearest star is about 400 miles away. The average distance between stars in this ping-pong ball galaxy is about 400 miles. And there are about 100 billion stars in the galaxy. Thinking of this model gives you an idea of the size and emptiness of a galaxy.

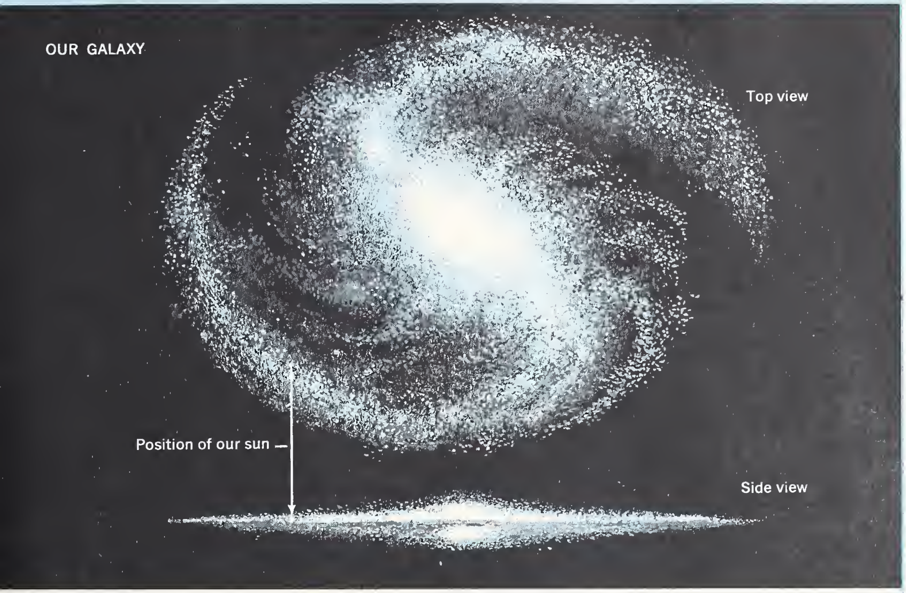
Nebulae is a Latin word for clouds. It refers to distant hazy spots in the sky. Many are faraway galaxies like our own; others are clouds of dust or gas within our galaxy.


Great Nebula in Orion


Trifid Nebula in Sagittarius

Ring Nebula in Lyra


Great Galaxy in Andromeda

Let us try a different scale for the galaxy. Imagine that our sun is the size of a grain of sand. In this model, the stars are about five miles apart. If you can imagine 100 billion sand grains five miles apart spread out in a flat disk, you have a pretty good idea of the galaxy.

Our galaxy is about 100,000 light-years in diameter, and the sun is about 30,000 light-years from the center. That puts it near one edge. The space between stars in the galaxy is not exactly empty. Bits of dust and hydrogen gas float in the space between the stars.

In the galaxy, each star has its own orbit around the center of the galaxy just as each planet has its own orbit around our sun. Stars near the center of the galaxy move more rapidly than stars near the edge. Thus, the stars in the galaxy slip by each other as the centuries pass. Every star in the galaxy has different neighbors now from those it had a billion years ago.

Developing the Lesson: These pages may be assigned for home reading. The amount of time spent in class discussion can be lengthened or shortened depending on the pace at which the pupils have been moving through the text.

The pupils may be interested in how these astronomical photographs were taken. The photographs shown on pages 184 and 185 were taken on color film at the Mt. Wilson and Mt. Palomar Observatories, using the 200-inch Hale telescope. Despite its enormous size, the 200-inch telescope can take a usable photograph that is only about 3½ inches in diameter. Beyond this size, there is too much distortion in the photograph; points of light become elongated and distorted. Ordinarily, this small field is perfectly satisfactory, because the astronomers are usually interested in only one particular star, and they make sure that this star is in the center of the photographic field.

TIME AND SPACE

Tonight, look at the stars. You will see each of them just as it was at some time in the past. The world's largest telescope can photograph objects two thousand million light-years away. This means that the light from these objects has been traveling through space for two thousand million years.

What was happening on the earth when the starlight that made each photograph below started traveling toward us? You can see in the picture below each photograph of the stars.

CLUSTER OF GALAXIES IN HYDRA

700 Million Light-Years Away

There were no hard-shelled forms of life on the earth 700 million years ago. But when the light from these galaxies had traveled one third of the distance toward us, trilobites were found in the seas.

CLUSTER OF GALAXIES IN CORONA BOREALIS

240 Million Light-Years Away

At the time light from this cluster started toward us, primitive amphibians were found in freshwater ponds and streams. Above, you see a photograph of the skull of one such amphibian, Diplocaulus.

THE GREAT CLUSTER IN HERCULES
35,000 Light-Years Away
This tooth from an ice-age elephant is 35,000 years old. When light from the Great Cluster in Hercules started toward the earth, these elephants lived near the great ice sheet that covered much of North America.

PLANETARY NEBULA IN AQUARIUS
600 Light-Years Away
This nebula with its jet-like streamers and luminous ring is one of the closest to us. If you look at it tonight, you will see it as it was when Geoffrey Chaucer was beginning to write his *Canterbury Tales,* in 1387.

The photographic film used was Anscochrome, since it was the fastest available when it was decided to take a set of special color photographs. Even then, the exposure times were very long, averaging an hour or two. The earth is, of course, rotating about its axis. This means that the 200-inch telescope had to be continually turned backwards to compensate for the rotation of the earth. The operating mechanism for the telescope does this very exactly, but not exactly enough for perfectly sharp photographs. Therefore, an astronomer had continually to make small corrections in the motion of the telescope to make sure that it was always pointing exactly where it was supposed to.

Photographic emulsions do not reproduce colors accurately, and even after the photographs had been taken and developed, special printing techniques had to be followed to compensate for the errors inherent in the film emulsion.

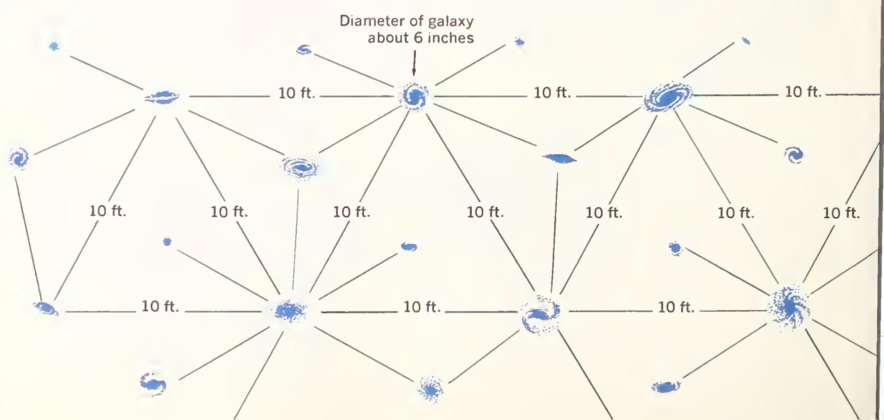
The Mt. Wilson and Mt. Palomar Observatories have made available for sale sets of color transparencies, which can be ordered from the observatories. The magazine *Sky and Telescope* lists many firms that sell other sets of color transparencies made at other observatories. It would be well worthwhile obtaining a set of these transparencies.

Almost all the objects you see in the sky on a clear night are in our own galaxy. But astronomers have studied thousands of faintly visible objects with telescopes and found these objects to be part of other galaxies. Thus, the universe is not made up of our galaxy alone, but in fact of billions of galaxies, each one with billions of stars!

Galaxies extend outward in all directions from our own as far as we can see with our most powerful telescopes. Nearer ones are about 150,000 light-years away. But galaxies have been discovered 5 billion light-years away. Some are surely farther away than that and may never be detected.

It is usually helpful to imagine a small model when thinking about astronomical systems. Here is a model of the universe for you to think about. If a single galaxy containing 100 billion stars were shrunk to the size of a fried egg, about six inches across, then the average distance to the next galaxy would be about ten feet. Imagine countless objects the size of fried eggs tipped in all directions, each one about ten feet from the next.

In one of these billions of galaxies, out near the edge, there is a medium-sized star. It moves around the center of the galaxy as do the other 100 billion stars in this galaxy. Looking very closely with special instruments, for the objects are small, we see nine planets that go around this star. The planet that is third in distance from the star is covered mostly by water. This planet has a moon. Every once in a while a tiny new satellite is shot off from this planet, and, like the moon, it moves in orbit around the planet year after year. Would you predict that in time we would see an object leave that planet and arrive on the moon, or even at a point on another solar system?



Using What You Have Learned

1. Make a papier-mâché model of several galaxies. Make each galaxy about six inches across and about ten feet from any other galaxy. Maybe you can fit four or five in your model. Remember that galaxies extend outward in all directions from each other.

2. If you live near a planetarium, plan to visit it when the program is about different models of the solar system.

3. Prepare a special report on comets. How are comets different from planets?

4. How old is our solar system?

5. We get information about astronomical objects from the light they give off. Light travels at 186,000 miles per second. At this speed light reflected from the moon reaches us in a second and a half. In other words, when you see the moon you see it the way it looked a second and a half ago. You see the sun the way it looked about eight minutes ago. You see the nearest star the way it looked four and one-half *years* ago. Can you see that as you look out in space you are looking backward in time? Discuss this idea with your classmates.

6. Why does our Milky Way Galaxy seem to be a narrow band of stars across the sky?

7. Use a part of your classroom bulletin board for sky studies. Form a committee to tack news about the sky on the board every week. You might tack such things as clippings from newspapers and magazines about the sky, daily or weekly timetables of sunrise and sunset, special events such as an eclipse or a meteor shower, directions for making a telescope, and photographs made by classmates of sky objects.

TEACHING SUGGESTIONS
(p. 187)

Background: The answers to *Using What You have Learned* are:

4. This is very theoretical. The best guesses are that the solar system is about 5 billion years old.

5. The fact that as we look outward into space we are looking backward in time is helping astronomers to understand the origins of the universe. When they view very distant stellar objects, they are seeing these objects as they looked several billion years ago.

6. Because of the position of the sun in the Milky Way, we are looking at the galaxy edge on.

TEACHING SUGGESTIONS
(pp. 188–189)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned: This is a summary of the entire unit, with new words in boldface type.

Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390-393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

WHAT YOU KNOW ABOUT

Astronomy

What You Have Learned

Models help scientists explain their ideas. Astronomers have used models to help them explain the motions of the planets in our solar system.

The **Ptolemaic** model is an earth-centered model of the solar system. The **Copernican** model is a sun-centered model. Both models were designed to explain the **retrograde motion** of the planets. Ptolemy believed that each planet went around the earth in two circles. One was a large circle that carried it around the sun. The other was a small circle the center of which was on the larger circle. The small circle was called an **epicycle.** Copernicus believed that the sun, not the earth, was at the center of the solar system. Scientists prefer the Copernican model because it is simpler.

The distance and size of the nearest planet and other heavenly bodies can be found by using **protractors** and **similar triangles.** The distance of the farther planets and of the stars can be found by measuring their amount of **parallax.** The unit of measurement used to measure the distance to the stars is the **light-year.**

Our sun is only one star in a large group of stars called a **galaxy.** There are billions of galaxies in the universe.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

epicycle	light-year	Ptolemaic model
galaxy	parallax	solar system

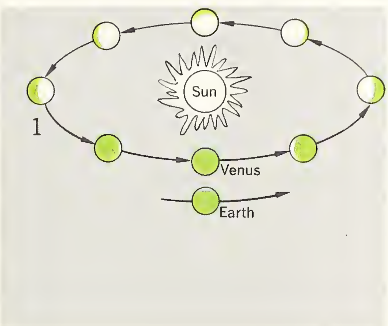
Complete the Sentence

Write the numbers 1 to 7 in your notebook. Next to each number write the answer that best completes the sentence.

1. The backward shift in position of a planet is called ___?___ ___?___.
2. The apparent motion of an object when viewed from two different points is called ___?___.
3. The size of an angle is measured with a ___?___.
4. The distance across a planet through its center is called the ___?___.
5. Distances beyond our solar system are measured in ___?___.
6. A large group of stars is called a ___?___.
7. The sun-centered model of the universe was devised by ___?___.

Can You Tell?

Look at the drawing below and tell why our view of Venus is constantly changing.



Complete the Sentence:

1. retrograde motion
2. parallax
3. protractor
4. diameter
5. light-years
6. galaxy
7. Copernicus

Can You Tell? The orbit of Venus is within the earth's orbit and nearly in the same plane with it. Because of this, Venus appears to oscillate to the east and west of the sun's position. At one point, as in the diagram showing Venus *above* the sun, its distance from the earth averages 160 million miles, or the sum of the earth's and its own distance from the sun. From this position Venus emerges slowly to the east of the sun as the evening star. It comes out a little higher from night to night and sets a little later after sunset. The entire westward movement is accomplished in 144 days. Midway, the planet passes nearly between the sun and the earth into the morning sky, as shown in the diagram.

TEACHING SUGGESTIONS
(pp. 190–191)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

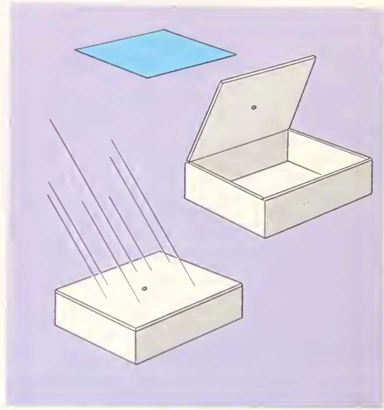
You Can Read: There are many excellent books on astronomy that you may wish to refer to for additional background material.

General titles that are useful include the following. *Exploration of the Universe,* by G. Abell (Holt, 1964). *Pictorial Astronomy,* by Dinsmore Alter et al. (Crowell, 1963). *Astronomy,* by R. H. Baker (Van Nostrand, 1964). *The Astronomer's Universe,* by B. J. Bok (Cambridge, 1959). *Elements of Mathematical Astronomy,* by M. Davidson (Macmillan, 1962). *Splendor in the Sky,* by G. S. Hawkins (Harper, 1961). *Astronomy,* by F. Hoyle (Doubleday, 1962). *A History of Astronomy,* by A. Pannekoek (Interscience, 1961). *Larousse Encyclopedia of Astronomy,* by L. Rudaux and G. De Vaucouleurs (Prometheus, 1962). *Astronomy of the 20th Century,* by O. Struve and V. Zebergs (Macmillan, 1962).

YOU CAN LEARN MORE ABOUT

Astronomy

You Can Make a Blueprint of the Sun's Path



Place a piece of blueprint paper in the bottom of a cigar box. Close the box. Make a small pinhole in the top. Place the box in sunshine for about six hours. Then take the box out of the sunlight and remove the blueprint. Place it in water to which you added a teaspoonful of potassium dichromate. You can buy potassium dichromate in a photography supply store. When your blueprint is developed, you will have a long arc showing how the sun moved across the sky.

You Can Visit an Observatory

These are some observatories in the United States:

Lowell Observatory
Flagstaff, Ariz.

Lick Observatory
Mt. Hamilton, Calif.

Mount Palomar Observatory
Mount Palomar, Calif.

Mount Wilson Observatory
Mount Wilson, Calif.

U. S. Naval Observatory
Washington, D.C.

Harvard College Observatory
Cambridge, Mass.

Princeton Observatory
Princeton, N.J.

McDonald Observatory
Mount Locke, Texas

Leander McCormick Observatory
Charlottesville, Va.

Yerkes Observatory
Williams Bay, Wisc.

You Can Visit a Planetarium

These are cities that have large planetariums that you can visit.

New York, N.Y.
American Museum-Hayden Planetarium

Chapel Hill, N.C.
Morehead Planetarium

Chicago, Ill.
Adler Planetarium

Colorado Springs, Colo.
U.S. Air Force Academy Planetarium

Boston, Mass.
Hayden Planetarium

Los Angeles, Calif.
Griffith Observatory and Planetarium

San Francisco, Calif.
Morrison Planetarium

Flint, Mich.
Longway Planetarium

Philadelphia, Pa.
Fels Planetarium

You Can Read

1. *Experiments in Sky Watching,* by Franklyn M. Branley. Directions for making astronomical devices and for doing experiments are included.
2. *Fun with Astronomy,* by Mae and Ira Freeman. Many experiments and projects are suggested.
3. *Worlds in the Sky,* by Carroll L. and Mildred A. Fenton. About the earth, the solar system, the stars, and the universe in general.
4. *Exploring the Universe,* by Roy A. Gallant. A history of astronomy.
5. *The Sky Observer's Guide,* by Newton and Margaret Mayall and Jerome Wyckoff. Many charts, tables, and illustrations.

Books on the moon include the following. *Pictorial Guide to the Moon,* by Dinsmore Alter et al. (Crowell, 1963). *Moon Atlas,* by V. A. Firsoff (Viking, 1961). *The Moon* by G. Gamow (Abelard, 1959).

Books on the planets include the following. *The Planet Saturn,* by A. F. O'D. Alexander (Macmillan, 1962). *Guide to Mars,* by P. Moore (Macmillan, 1960). *The Planet Venus,* by P. Moore (Macmillan, 1961). *Earth, Moon and Planets* by F. L. Whipple (Harvard, 1963).

Books on the earth as a planet include the following. *The Double Planet,* by I. Asimov (Abelard, 1960). *Our Earth,* by A. Beiser (Button, 1959). *Planet Earth,* by K. Stumff (University of Michigan, 1959).

Films:

The Astronomer (16 min., color, International Film Bureau).

Constellations: Guides to the Night Sky (11 min., color, Indiana).

Earth Satellites: Explorers of Outer Space (17 min., color, Encyclopaedia Britannica Films).

The Solar System (10 min., color, Coronet).

What Are Stars Made Of? (16 min., color, International Film Bureau).

Universe (25 min., color, McGraw-Hill).

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 3. To find order in the natural environment, the scientist seeks basic units that can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.

Key Concept 6. There is a basic tendency toward stability or equilibrium in the universe; thus, energy and matter may be transformed, but the sum total of matter and energy is conserved.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. The idea that light is made up of particles can be used to explain some of the behaviors of light, namely: light travels through empty space; it travels in straight lines; it has a measurable speed;

6

Other concepts appear under "Learnings" in the Orientation to each lesson found in the Teaching Suggestions.

The Nature of Light

How Light Behaves

How Light Is Reflected

Light in Different Substances

The Wave Idea of Light

it is reflected; it forms images; it is bent (refracted) when it enters a different substance.

2. The idea that light is made up of waves can be used to explain the above, plus diffraction (bending of light as it passes a sharp edges).

PROCESSES:

- Observing—Pages 198, 202, 204, 206, 208, 209, 210, 211, 212, 213, 215, 216, 220, 222, 224, 226.
- Experimenting—198, 206, 212, 213, 215, 220, 222, 224, 226.
- Comparing—198, 202, 204, 206, 208, 209, 210, 211, 212, 213, 215, 216, 220, 222, 224, 226.
- Inferring—198, 202, 204, 206, 208, 209, 210, 211, 212, 213, 215, 216, 220, 222, 224, 226.
- Measuring—206, 208, 209, 210, 212, 213.
- Selecting—198, 202, 216, 228.
- Demonstrating—197, 204, 206, 208, 209, 210, 211, 216, 217, 228.
- Explaining—202, 208, 209, 210, 211, 213, 216, 217, 228, 229.
- Hypothesizing—205.

TEACHING SUGGESTIONS
(pp. 194–195)

LESSON: How does the particle theory of light explain how light travels through space?

Background: The two main theories for the behavior of light are the *particle,* or corpuscular, and the *wave.* In this unit, the particle theory is discussed first, for two reasons: the particle theory came first historically, and it is easily comprehended by the pupils. It also provides you with an opportunity to show the pupils how a theory that explains all the facts must be modified or discarded when it fails to explain newly discovered facts. The wave theory can then be introduced to explain wave phenomena, which the particle theory cannot account for.

Learnings to Be Developed: Light travels through space.

In a dark room, shine a flashlight on a wall. Now put a book in front of the flashlight. What happens? You have just learned two facts about light: light travels, and light does not pass through certain materials. It is easy to observe the ways that light behaves, but it is not so easy to explain them.

How Light Behaves

Scientists have been trying to explain the behavior of light for many centuries. As more is learned about light, earlier explanations are given up because they do not fit the facts.

In this unit you will learn, in part, how today's scientists explain light. You will also learn why scientists are still searching for more complete explanations of some of the behaviors of light. When you complete the unit, you should understand how scientists develop theories about things they observe and how they test these theories.

It is difficult to describe light. You cannot take light in your hand and examine it. Light can be described only by its actions. Yet scientists have ideas about what light is, and they can test these ideas. How do today's scientists explain light?

One idea is that light is made up of tiny particles that move very rapidly, like bullets shot from a machine gun. These "bullets" are shot from a source of light, such as the sun or a candle flame. Isaac Newton developed the **particle theory of light** in the late 1600's. He called the light particles **corpuscles** (KOR-puss-'lz).

Let us test the particle, or corpuscle, idea to see how well it explains light and how light acts.

Light Can Travel Through Empty Space

Look carefully at the picture on page 195.

Imagine that the bulb and the screen are very far apart and that there is nothing between them—not even air. The bulb is turned on. Light is on its way from the bulb to the screen. Until the light reaches the screen, nothing can be seen. When the light strikes the screen, the screen will bounce, or reflect, the light into your eyes. Only then will you know that there is light.

How does what is happening in the picture explain how you are able to see the sky?

The same thing happens when the sky is lit up during the day. Here the source of light is the sun. Sunlight travels through space. When it strikes the air that surrounds the earth, you see the "sky."

On clear nights, light from the stars reaches your eyes after traveling through millions of miles of space. The light from some very distant stars will not reach the earth for years.

Does the particle idea of light explain how light travels in empty space? You can test this idea by comparing the way light travels with the way sound travels.

If you are near a wall and someone on the other side taps it, you will hear the tap. The wall carries the sound. If you put your ear to a table top, you can hear the ticking of a watch on the opposite end of the table. The table carries the sound. If you ring a bell, a person across the room can hear it. What carries the sound this time?

If you hang the ringing bell in a jar from which some of the air has been pumped out, the bell will not sound as loud. If all the air is pumped out, the ringing bell will not be heard at all. Do you remember the name of the English scientist who first did this experiment? He showed that sound must be carried through a substance. Sound cannot travel through empty space.

Sound travels in waves, and waves change the substance through which they travel. They cause the substance to vibrate, or move with a back-and-forth motion. Therefore, when we talk about sound waves' traveling, we are really talking about something that is happening to a substance. But light does not depend on something through which to travel; it can travel through empty space. Particles do not need a substance through which to travel. The particle idea of light explains why light can travel through empty space.

Developing the Lesson: Though the pupils may have heard of a vacuum, it is doubtful that they have ever had occasion to think seriously about what "vacuum" means, and you might take this opportunity to contrast the behavior of light and the behavior of sound as they travel from one point to another. Sound travels through both solids and air, but it cannot travel through a vacuum because in a vacuum there is nothing for the sound waves to travel in. Examples from space exploration are interesting. In space, an astronaut would not hear a sound (assuming he could take off his helmet), no matter what banging, roaring, or knocking were going on about him. You can contrast this behavior with that of light, which can travel through a perfect vacuum with the greatest of ease. You can conclude the discussion by explaining how obvious it is that this light must be made up of solid little particles of energy, and that the experiment on page 196 will show how these particles behave.

Follow-Up: On page 195, the statement that when sunlight strikes the air, one sees the "sky" refers to the fact that certain wavelengths of light are reflected while others are absorbed, producing the total effect of a blue color.

TEACHING SUGGESTIONS
(pp. 196–197)

LESSON: How do particles of light travel?

Background: The experiment attempts to show, by analogy, how particles of light must behave if they are to explain the observed properties of light. One of these observed properties is the casting of shadows, an illustration of which is shown on the next page. The main point to watch in the experiment is that the table is level; otherwise the marbles will follow curved paths. If a flat surface is not available, an alternative experiment is rolling the marbles swiftly towards the dominoes, somewhat as in a bowling alley. Some of the dominoes would be shielded by the brick, of course.

Learnings to Be Developed:

Light is made up of particles.

Light travels in straight lines.

Developing the Lesson: The manner in which the experiment can be conducted is explained above. The analogy is not exact, however, because the marbles will curve. You can bring this point up during the experiment, and the pupils should appreciate that in their experience all objects follow curved paths. It is also their experience that the faster objects move,

Light Usually Travels in Straight Lines

When an object casts a shadow, it blocks out the light from the area in shadow because light travels in fairly *straight* lines.

You can demonstrate how shadows result from the straight-line motion of light. Since you cannot use real light particles, you can use other particles, such as marbles, to help you understand the behavior of light.

EXPERIMENT

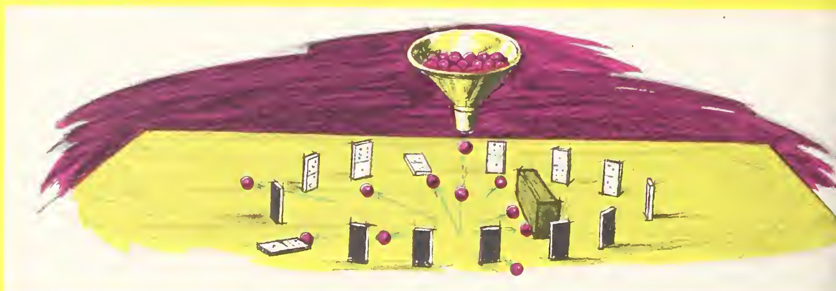
How Does the Straight-Line Motion of Light Produce Shadows?

What You Will Need

large funnel	40 marbles	smooth, level table
14 dominoes	large brick	or floor

How You Can Find Out

1. Set up the dominoes in a small ring.
2. Place the brick to one side of the center, as shown in the picture.
3. Drop the marbles from the funnel into the center of the ring.

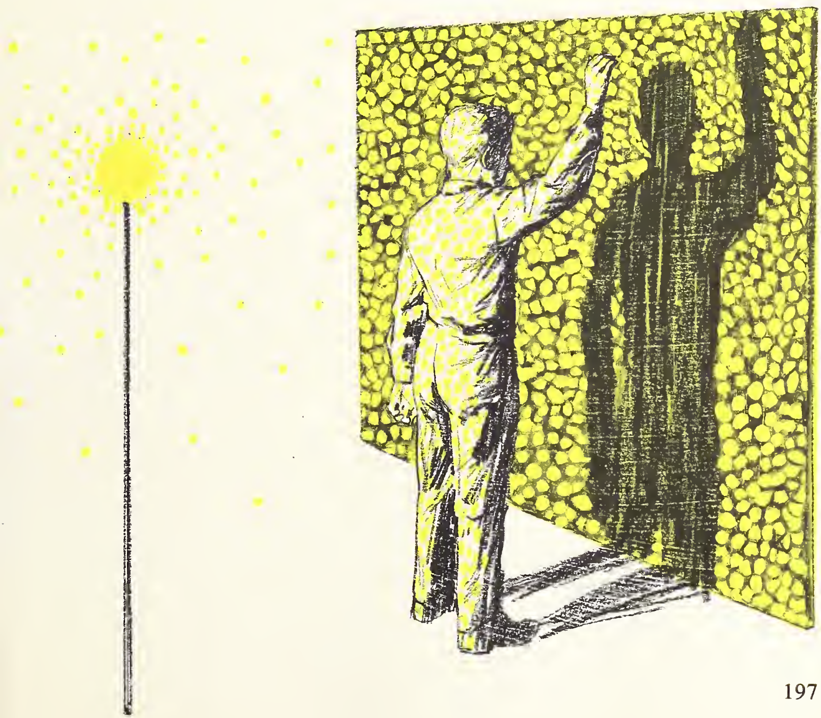


Questions to Think About

1. Which dominoes remain standing?
2. Can you explain why they remain standing?

The marbles act like particles of light. They move in straight lines. The brick casts a kind of "shadow." The marbles cannot strike the dominoes that are shielded by the brick.

Now think of an explosion of tiny particles, such as the one in the picture. After the explosion, each particle travels at a high speed. A person standing in front of a wall would block or absorb some of the particles. The particles reach every part of the wall except the part that is blocked by the person. That part is dark. Because the particles travel in straight lines, they cannot reach that part of the wall. A shadow of the person blocking the particles of light is formed on the wall. The particle theory of light, then, explains the fact that shadows are formed.



the straighter they move. But this is always a matter of degree. No matter how swiftly objects move, even bullets or self propelling rockets, they always follow curved paths. You can bring this out by questioning the pupils. Some may realize that this is due to the force of gravity (which has already been discussed), but the particles of light are traveling at such a terrific velocity that even the force of gravity has no effect on them.

○ **ADDITIONAL ACTIVITIES:**

Obtain a small, intense source of light. An unshielded light bulb will do, if nothing else is available. Darken the room and turn on the light bulb. Have the pupils observe the shadows and ask why such shadows are not usually seen in the classroom. The pupils should be able to explain that there are many sources of light in the room. These lights cast many shadows but the shadows are washed out by other lights.

TEACHING SUGGESTIONS
(pp. 198–199)

Background: Albert Abraham Michelson's career is an example of how single-minded devotion to one idea can have widespread ramifications in both practical engineering and theoretical physics.

Michelson was fascinated by the problems posed in measuring the speed of light, and the solution of these problems led not only to the measurement of the speed of light with new standards of accuracy, but also to his invention of the interferometer (which is now widely used in both industry and laboratories where the highest precision of measurement is necessary), to the redefinition of the standard length of the meter in terms of the wavelength of light, to the invention of echelon gratings for spectroscopes when the highest possible resolution is desired, and to the overthrow of the concept of an ether that pervaded space and enabled light to travel through space. The absence of an ether led directly to the development of the theory of relativity by Einstein.

The top illustration on page 198 shows Michelson's first interferometer. A beam of light from the lamp housing is split into two beams by a partially silvered set of

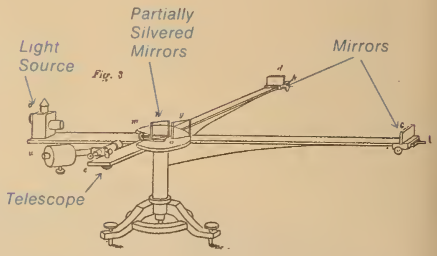
Albert A. Michelson

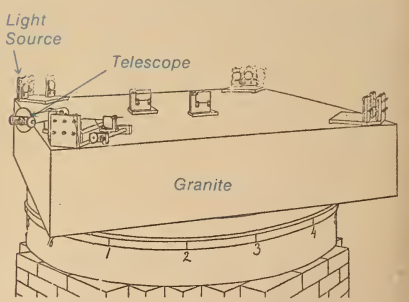
(1852–1931) United States

If you want to measure something in inches, you use a ruler. If you want to weigh yourself, you step on a scale. But how would you measure the speed of light? Light travels 186,000 miles per *second*. This speed means light could travel eight times around the earth at the equator in the time it takes you to snap your fingers twice.

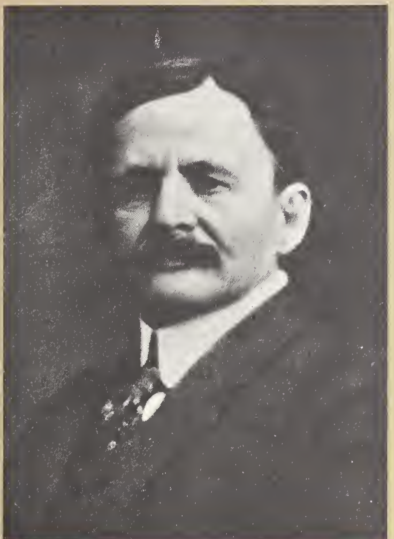
Why is it important to measure the speed of light? When scientists observe the stars, they want to know how far away the stars are. To know this, the scientists must know how long it takes for the starlight to reach the earth. The distance that light travels in one year is called a light-year. A light-year is the unit of measurement scientists use to measure distances in the universe. The more accurately they know the speed of light, the more accurately they can measure the universe.

In 1868, when Albert Michelson was sixteen years old, he entered the United States Naval Academy at Annapolis to become a naval officer. Two years after he graduated, he became an instructor there. He read that two famous French scientists had measured the speed of light very accurately. Michelson became interested in their experiments and built





Suitable books for the pupils include Michelson and the Speed of Light, by Bernard Jaffe (Anchor, 1960) and Albert A. Michelson, America's First Nobel Prize Winner, by John H. Wilson, Jr. (Messner, 1958). Michelson described his experiments in a series of lectures given in the early 1900's and later published. This book, Studies in Optics, has been reprinted as a paperback by the University of Chicago.



a machine like the one the Frenchmen used. He spent $10.00 of his own money to do this. To his astonishment, Michelson was able to measure the speed of light even more accurately than the two famous scientists had measured it.

Michelson decided to become a scientist. He resigned from the U. S. Navy and went to Germany, where he studied physics. He later invented machines that could measure in millionths of an inch. He also discovered a way to measure the size of a star. But his most famous accomplishment was to measure the speed of light more precisely than anyone had before.

The pictures on page 198 show the machines he designed to do this. The wheel with the eight mirrors reflects a flash of light to a mirror on a mountaintop 23 miles away. If the wheel is turning at the correct speed, the flash of light will be reflected back into the eye of the observer from another mirror. This will happen only when the wheel is turning at one particular speed. Knowing how fast the wheel is turning, Michelson was able to calculate how fast the flash of light traveled. For his accomplishment, he was awarded the Nobel Prize for physics in 1907. Albert Michelson was the first American to receive this distinguished award.

mirrors and directed to two reflecting mirrors at right angles to each other. The two beams are recombined at the partially silvered mirrors and directed toward a small telescope. If there is any difference in the distance that the beams of light have travelled, the difference will show up as interference fringes at the telescope. By measuring the distance between the fringes, it is possible to measure the difference in speeds.

With this instrument, Michelson hoped to measure the difference in the speed of light parallel to and at right angles to the motion of the earth through the ether, which, according to theory, existed. This first instrument was too lightly constructed—footsteps outside the building in which it was housed were sufficient to upset the calibration.

The illustration at the bottom of page 198 shows a later version of the interferometer. This is the instrument that showed no ether existed in space. The optical parts rested on a granite slab, which itself floated on a pool of mercury, which gave both solidity and rigidity and effectively dampened out any external vibrations.

TEACHING SUGGESTIONS
(p. 200)

Background: The answers to *Using What You Have Learned* are:

1. a. The speed of light is approximately 186,200 miles per second.

b. The speed of sound is about 1,100 feet per second. Therefore, light travels about 900,000 times faster than sound.

c. A light-year is the distance light travels in one year.

2. Natural sources of light, besides the sun, are other stars, lightning, fireflies, angler fish, and certain bacteria. Other natural sources of light are mainly wood or petroleum products — oil, kerosene, whale oil, wood fires, etc. These men have used for their own needs.

3. The sun would not be seen in the area of the *umbra*, or moon's shadow (A). Partial vision of the sun would be possible in the *penumbra*, or partial shade area (B), and all of the sun could be seen from the horizon of the earth as seen in the diagram.

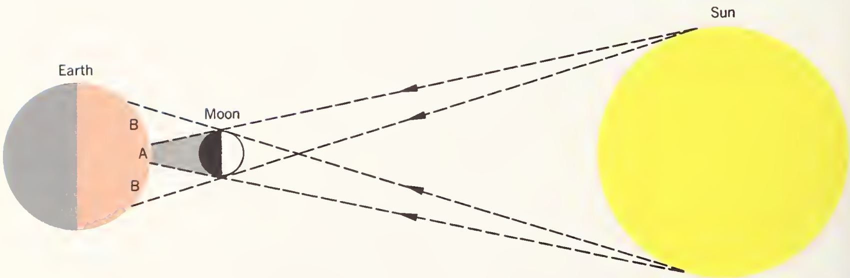
Using What You Have Learned

1. Find out about the speed of light. Look for answers to these questions:

a. At what speeds does light travel in various substances?
b. How does the speed of light compare with the speed of sound?
c. How do scientists use the unit of measurement called the light-year?

2. Find out about sources of light. What things, besides the sun, are natural sources of light? What has man used as sources of light?

3. On the basis of what you have read about shadows and the way light travels, explain what happens during an eclipse of the sun. Study the picture on this page. From where do you think the sun would not be seen at all? From where would only part of the sun be seen?



1. In area of total shadow (A)
2. In area of partial shadow (B)

How Light Is Reflected

The ways light is *reflected* is a key property of light.

What happens when a ball hits a surface? It bounces back. The same thing happens to light. When light particles strike an object, they bounce back from it. We say that they are *reflected*. Light particles reflected from

OBSERVATION

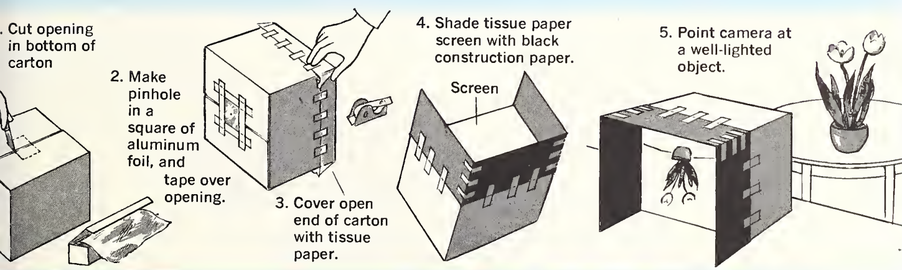
How Is an Image of an Object or Scene Formed?

What You Will Need

pinhole camera tissue-paper screen

How You Can Find Out

1. Follow the directions for making a pinhole camera shown below.
2. Darken the room.
3. Place the camera so that the pinhole faces the window.
4. Look at the image formed on the tissue-paper screen.



Questions to Think About

1. What do you notice about the image?
2. Why is the pinhole camera image not very bright?

TEACHING SUGGESTIONS
(pp. 201—203)

● **LESSON:** How does light form an image?

Background: The preceding pages established that light consists of particles that travel in straight lines; the next few pages develop the consequences of this fact. Notice, also, that the experiment described on page 202 is a *thought* experiment. The pupils are invited to imagine "what would happen if." The actual activity would be difficult to do accurately, and scientists often use thought experiments to test theories.

Learnings to Be Developed:

Light forms images.

Because light travels in straight lines, the image we see in a camera is actually upside-down.

Developing the Lesson: You can begin the discussion with a short review of the preceding lesson. Then ask:

• *How is it possible for a person looking through a knothole in a fence to see everything on the other side of the fence?*

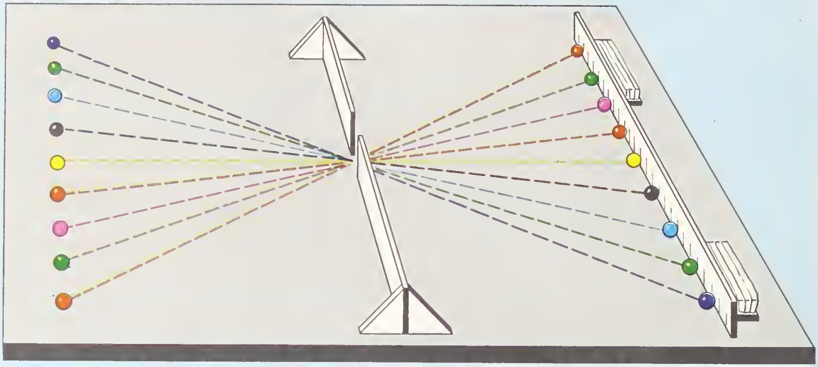
The question may baffle the pupils. But remind them that light does not travel from a person's eyes to the objects he sees; the light travels from the objects to his

eyes. The point being made is that every object in view either reflects or gives off particles of light, and this is what is meant when one speaks of "seeing" objects. It is rather remarkable that all these particles travel to every point—every little knothole—within their field of view. Then ask:

- *How does the light behave once it is past the hole?*

Discuss with the class the imaginary experiment on this page and the observation on page 201.

Follow-Up: The pinhole camera can be assigned for making at home by those who are interested in making it. The cameras can be exhibited in class and their operation observed. You may also be able to obtain an old view camera with a ground glass screen. Many camera shops will rent you one at a reasonable charge. The images obtained with this camera are much clearer and sharper than can be obtained with a pinhole camera, and they will prove more useful in class discussions. When discussing the path that light takes in traveling through a camera, it would be helpful to draw a camera on the chalkboard and then illustrate the discussion by drawing the particles of light as they enter the camera and strike the film at the rear.



an object form an image of the object on another surface. That is how we see things. Light reflected from an object enters our eyes through the pupils. An image of the object is formed on the *retina*, which is located on the rear inner wall of the eye. The retina acts as a screen. When nerve messages from the retina reach the brain, we see the object. Find out more about the retina and the images formed on it.

The particle idea of light, which represents light as particles traveling in straight lines, can be used to explain the upside-down image in the pinhole camera. Imagine a row of marbles set up in front of a ridge, as in the picture above. The opening in the ridge is just big enough to let one marble through. Now suppose that the marbles were shot through the opening. The marbles would land against the

yardstick on the other side of the ridge.

Study the picture again. Because each marble travels in a straight line, the one at the top of the row goes through the opening and ends up at the 32-inch mark on the yardstick. The sixth marble in line ends up at the 14-inch mark. The bottom marble in line ends up at the 2-inch mark. Looking at the positions the marbles take, can you explain the upside-down image?

Mirror Images

A mirror reflects light so well that it shows clear images of objects. What things besides mirrors show images? Now think of some things that do *not* reflect light well enough to show images. What do you think is the difference between the two groups of things?

Can you show the difference in reflections given by smooth and rough surfaces? Several ping-pong balls, a shallow box of gravel, and a smooth table are needed.

Have a friend stand at the opposite end of the table. Bounce the ping-pong balls toward him, one at a time. Now substitute the shallow box of gravel for the smooth table. Bounce the ping-pong balls against this surface. Could your friend easily catch the balls you threw on the table? Did it become more difficult to catch them when the surface changed?

Now stand to the side and observe while your friend throws the balls on the smooth table. Ask him to throw the balls at different angles. Notice how each one bounces off. If you

TEACHING SUGGESTIONS
(pp. 203–205)

● **LESSON:** How does light behave when it strikes a polished surface?

Background: These pages discuss another consequence of the straight line motion of particles of light: the way in which light is reflected by mirror surfaces. Smooth surfaces, such as glass or polished metal, reflect rays of light in a regular manner. They therefore produce mirror images. Rough surfaces reflect rays of light in an irregular manner, and they therefore do not produce mirror images. The activity with the ping-pong ball illustrates the fact that light is reflected from a flat surface at an angle identical to that at which it strikes the surface. The law also applies when light is reflected from rough surfaces, but because of the number and variety of angles encountered, the light is reflected in many directions, so that is is diffused.

Learnings to Be Developed:

Light can be reflected.

Mirror images are the result of the regular reflection of particles of light.

Developing the Lesson: Discussion can begin with a reference to the previous lesson, in which pinhole cameras were discussed. In that

lesson, the pupils learned that when the light passes through a small hole, the image is turned upside-down. The safe effect is visible every time they look in a mirror.

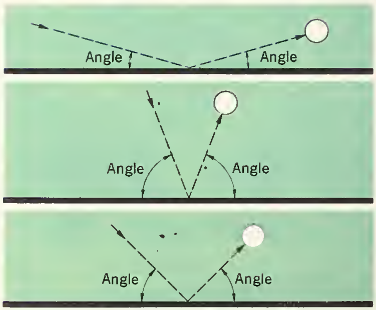
Why are right and left reversed when you look into a mirror? In this case, it is because of the way that a particle of light is reflected from a smooth surface into the eyes. This can be illustrated by drawing a diagram on the chalkboard, showing a top view of a person's head, the mirror, and the path taken by the particles of light. If the lines are drawn in a smooth, regular manner, the discussion can then lead to the idea that the mirror has reflected the particles of light into the eyes through equal angles. This is the point made by the boys throwing a ping-pong ball to each other on pages 203 and 204.)

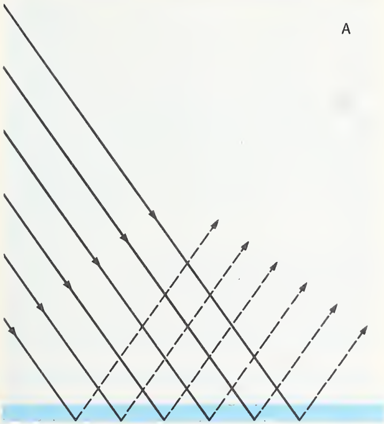
ADDITIONAL ACTIVITIES:

Here is an activity that shows how far behind a mirror an apparent image seems to be. Stand a piece of glass vertically and have a pupil view a bright object, such as a candle, in the glass. Then have another pupil move his finger behind the glass until it appears to match the reflected image in position. If the distance of the actual object to the glass and the distance of the

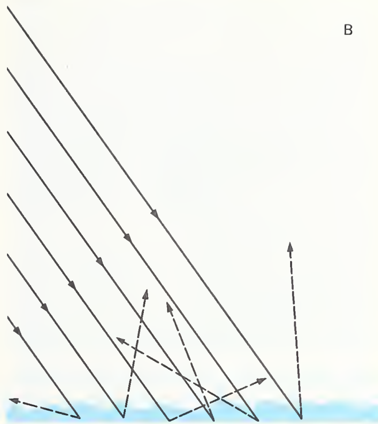
could measure the angles, you would find that the angle at which each ball bounces off is equal to the angle at which it is thrown. Study the diagrams on the bottom of this page to see this fact illustrated.

How would you go about measuring the angles? What do you find in each case?





Regular reflection



Irregular reflection

How do the light particles bounce off each of the surfaces shown above?

Light particles are like the ping-pong balls. The angle at which a light particle bounces off a surface is equal to the angle at which it hits the surface. When light particles strike a very smooth surface, they are reflected evenly, as shown in figure A, and a clear image is formed. When light particles strike a rough surface, they are reflected in many directions, as shown in figure B. The light is scattered, and a clear image is not formed. Remember that light particles are very tiny. A roughness that you could hardly feel might be very big in comparison to a light particle. As you know, most surfaces do not reflect images.

You have learned that when a shiny surface reflects light to your eyes, all the light that reaches your eyes is reflected from the same spot on the shiny surface. Look at figure A. Compare the angle at which the light strikes the surface with the angle at which it is reflected. Why do no other spots on the smooth surface reflect light to your eyes?

Now look at figure B. Why, when a lamp lights a rough surface such as blotting paper, does the entire surface seem to be fairly evenly lighted?

reflected image are measured, they will be seen to be equal.

The pupils can collect samples of different objects and compare their abilities to reflect. They might then examine these objects in detail and discover why each object does or does not reflect light, and whether these objects confirm their ideas about reflection.

(pp. 206–209)

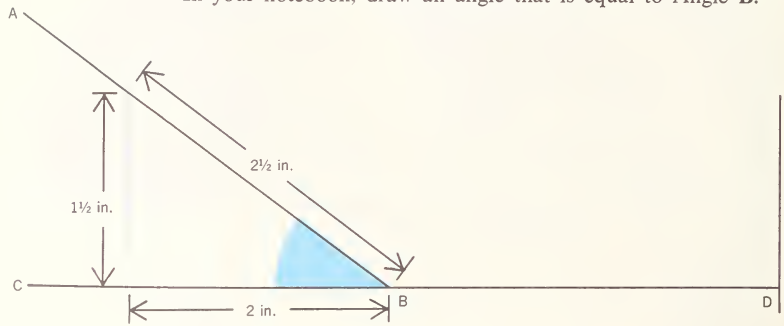
Background: The answers to *Using What You Have Learned* on pages 206-209 are:

1. The pupils can duplicate Angle B by copying the right triangle shown in the text. They should understand that if they are given an acute angle, they can always draw a line perpendicular to one of its sides (the dotted line shown in the text) to create a right triangle. They can then easily duplicate the triangle. Pupils may at this level have had little experience using compasses to construct geometric figures. For this activity measurement of the sides with a ruler and careful drawing of a square corner for the right angle are adequate.

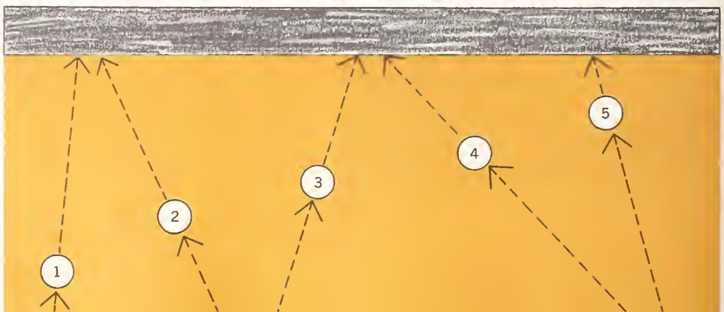
2. In the second problem, be sure that pupils show in their drawing that each ball rolls away from the wall at an angle equal to the angle at which it struck the wall. Pupils might used protractors to draw the second line in each pair. However, it is perfectly adequate in this case for them to approximate the second line, as long as they understand the basic principle. Light particle and ball both reflect (rebound) from a surface. The angle of impact (incidence) is equal to the angle of rebound (reflection).

Using What You Have Learned

1. In the diagram below, the line from **A** to **B** meets the line from **C** to **D** at an angle. Let us call it Angle **B**. If you had no way of measuring Angle **B**, how could you draw another angle equal to it? (Hint: How do you think the angles of two matching triangles compare with each other?) In your notebook, draw an angle that is equal to Angle **B**.



2. John rolled five balls to a wall. Each time he stood in a different place. The floor was perfectly smooth. The drawing shows the path of each ball and the spot where it hit the wall. On a separate sheet of paper, copy the drawing exactly. Now, on your drawing, show the path each ball took as it rolled away from the wall. (Do not draw in this book.) How is the behavior of each ball like the behavior of a particle of light?



3. Have someone stand at the front of the classroom and hold a mirror straight up and down. (Or, if you can, mount a mirror flush against a wall at eye level.) Ask one person in the class to name an object he sees in the mirror. Stretch a string from that person's position to the mirror and from the mirror to the object he sees. Examine the angles at which the string comes to and goes away from the mirror. Repeat this activity with two more people. What does this show?

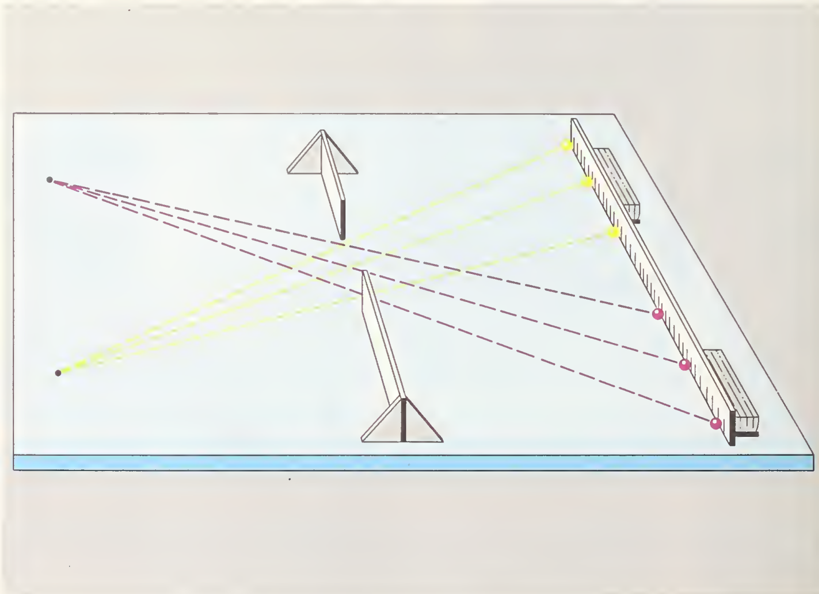
3. This activity should show that the angle at which light strikes the mirror is equal to the angle at which it bounces off. A variation on this experiment is to place a large piece of cardboard on the table in front of a vertical mirror. From an angle, a pupil sights a reflection of a pin stuck in the cardboard. The sighting is along a ruler or some other straight edge. Then a line is drawn from the observer's eye to the mirror along this line of sight. From the point at which this line hits the mirror, another line is drawn toward the pin. It will be seen that the angle of reflection equals the angle at which the light from the object strikes the mirror.

4. The thought experiment on page 208 should present no particular problem. Since the light from any one spot might reach more than one place on the film, the image is fuzzy.

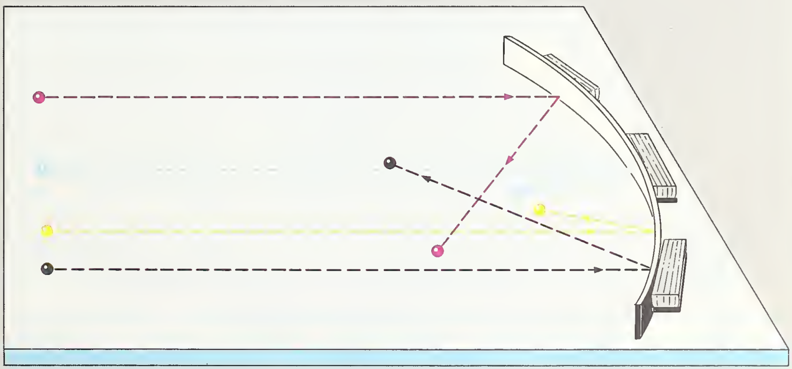
4. A pinhole camera with a tiny hole to let in light will form a distinct, but not bright, image. Make a camera with a hole larger than the one in the camera that you made before (page 201). Notice what happens to the image.

To understand the results better, imagine that you are shooting marbles through an opening in a ridge such as the one described on page 202. This time, however, the opening is about three times as big. Imagine shooting several marbles from the same spot. Would they all land at the same spot on the yardstick on the other side of the ridge?

In your pinhole camera, the spreading of light particles that come from the same spot results in fuzziness.



5. Find out in what ways a photographic camera is like the pinhole camera that you made. Find out in what ways it is different.



6. The particle idea of light can be used to explain the behavior of light in an auto headlight, which has a curved reflector behind the light bulb. Roll marbles straight against a curved surface as shown in the picture. What do you observe?

5. The pinhole camera and the photographic camera are alike in that light enters and behaves within the camera in the same way. They are different in that the photographic camera has a lens to sharpen the image, there is an unexposed film at the other end on which the light can make an exposure, and it has many mechanical devices to make the operation of the lens and film easy and automatic.

6. When the marbles, representing particles of light, are shot in parallel lines against the concave surface, the paths in which they rebound cross at one point. In other words, there is a focus. Suppose, now, that a source of light were placed at this focus. Since light can travel in either direction along a path, the paths at which the light strikes and at which the light is reflected are interchangeable. Striking the curved surface (at the same angles at which the marbles were reflected) the marbles will be reflected in parallel lines—at the same angles at which the marbles were shot. In an automobile headlight, a bulb is placed so that its light will strike a curved surface behind it and be reflected in parallel beams ahead of the car.

(p. 210)

Background: This section introduces the idea of refraction—how light behaves when it passes from one medium into another medium having a different density. The behavior of light under these circumstances is covered by Snell's law of refraction, which states that the angle of refraction depends on the indexes of refraction of the two mediums, and the sine of the angle at which the particle of light strikes the second medium. When light passes from a less dense to a denser medium, the light is bent toward the normal. When light passes from a denser to a less dense medium, the light is bent away from the normal. An imaginary perpendicular to the surface is called the normal. Thus, the more directly the particles of light strike the second medium, the greater the proportion of light that is refracted. The more glancing the light, the more is reflected and the less is refracted.

The underlying concept of this experiments is that if light consists of particles of energy, then light should behave as do other kinds of particles.

Light in Different Substances

Light travels at different speeds in different substances. It travels fastest in empty space. It travels faster in air than in water or glass. You can use marbles, water, and molasses to experiment and find out whether or not objects move at different speeds through different substances.

EXPERIMENT

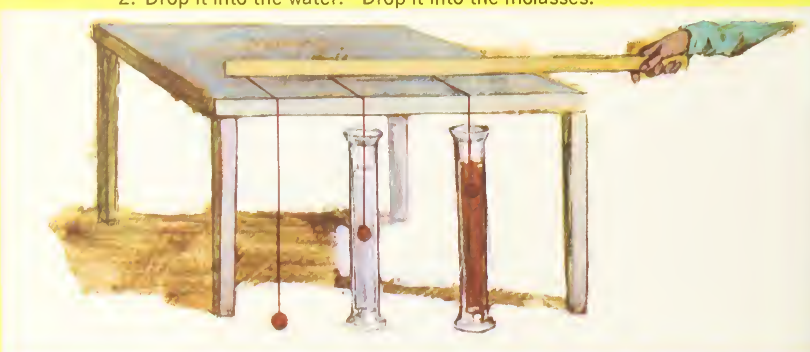
Do Objects Move at Different Speeds Through Different Substances?

What You Will Need

tall jar of water   marble   tall jar of molasses

How You Can Find Out

1. Drop a marble to the floor. Note its speed.
2. Drop it into the water. Drop it into the molasses.



Questions to Think About

1. How does the speed in air compare with that in water?
2. How fast does the marble move in molasses compared with its speed in air and water?

Particles of light, like the marbles, may travel at different speeds through different substances. Therefore, the speed of light particles may be changed by a change in the substance through which they are traveling. They may speed up or slow down as they pass from one substance into another.

OBSERVATION

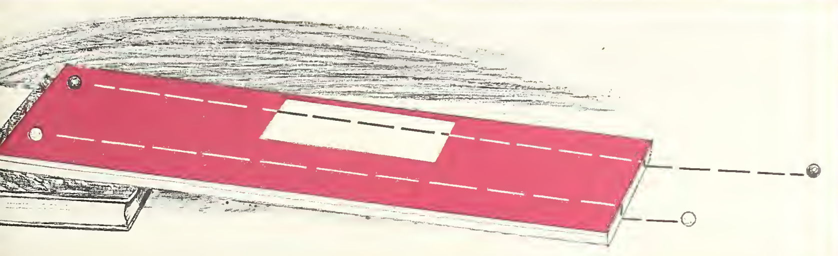
Why Does a Pencil in a Glass of Water Appear Broken?

What You Will Need

marbles
felt pad
book
smooth paper

How You Can Find Out

1. Put a pencil into a glass half full of water. Record your observations.
2. Use the particle model of light to explain what you see.
3. Set up the felt pad, paper, and books as in the picture.
4. Roll the marble down the pad so that it crosses the paper.



Questions to Think About

1. How does the direction of the marble change as it rolls over the paper?
2. Can you now explain why a pencil in a glass of water appears broken?

TEACHING SUGGESTIONS
(p. 211)

LESSON: Why does a pencil in a glass of water appear broken?

Background: The intent of this observation is to illustrate that a marble changes its direction when it changes speed. Since we are assuming that light also consists of solid particles, the light should also change its direction when its speed is changed. It is for this reason that a pencil in a glass of water appears to be bent.

Learnings to Be Developed: The refraction of light makes a pencil in a glass of water appear broken.

Developing the Lesson: Review with the class the information about moving marbles that has already been described on page 210. Rolling a marble down an incline is the same thing as having the marble move in slow motion. In the experiment, do not have the marble travel straight down the incline, as this would merely be equivalent to a particle's moving perpendicularly from one medium to another — no refraction will be evident. The marble should instead move down the incline at a slight angle from the perpendicular. Rolling two marbles down the incline at the same moment, one of which passes over the paper, will be more effective.

(pp. 212–214)

LESSON: How does a particle of light behave when it enters a different medium?

Background: The pupils often are confused about the direction of motion and the presumed density of the medium represented by the slopes of the checkerboard. When the marble is released, it is traveling relatively slowly. As it crosses the bent edge of the checkerboard, its speed increases and it turns more toward the perpendicular (or *normal,* as it is also called). This motion represents the passage of a particle of light as it travels from a dense medium into a less dense medium, as from water into air. In this sense, the activity represents the motion of a particle of light as it travels from the fish to the eye of the girl. Notice, however, that the analogy between the behavior of the rolling marble and that of a particle of light breaks down at this point.

As shown in the activity, the marbles move faster as they turn the edge of the checkerboard, and they also turn *toward* the perpendicular. As may be seen in the illustration with the goldfish, particles of light will move *away from* the perpendicular when they enter a less dense medium.

How Light Behaves When Its Speed Changes

You know that light travels through different substances at different speeds. When it enters a new substance in which its speed changes, it bends. The bending is caused by the change in speed.

Try another method to show how the path of particles bends when the particles suddenly change speed.

Place one half of a checkerboard on a book. Let the other half slope down. Roll a marble across the level part and down the slope. Does the marble change direction?

In the top diagram on the right, a ray of light is shown moving at a slant from water to air. In the bottom diagram, the ray is shown moving from air to water. In each, there is a line *perpendicular* to the surface of the water where the light strikes the surface. This line is called the *normal.*

The dotted lines show how the light would move if it continued in a straight line. When light moves from water to air, it bends away from the normal. When it goes from air to water, it bends toward the normal. The bending of light when it enters a different substance is called **refraction** (rih-FRAK-shun).

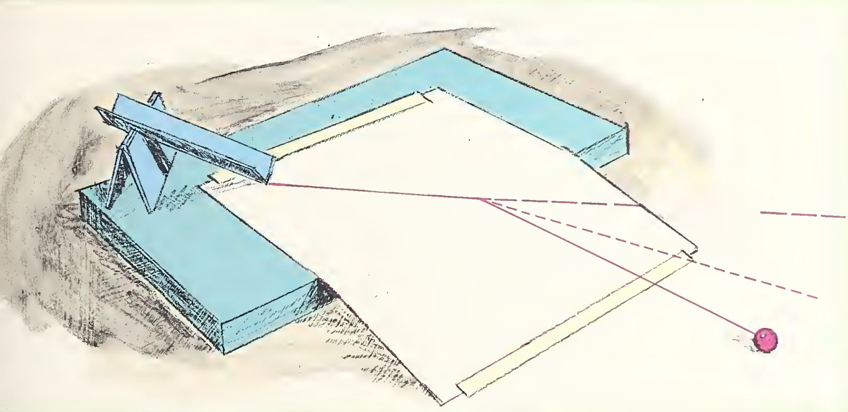
Do Fast-Moving Particles Bend Less Than Slow-Moving Ones?

What You Will Need

piece of cardboard	flat board	sheet of paper
marble	level table	tape

How You Can Find Out

1. Place the board on the table.
2. Tape the paper to the board so that the paper slopes gently to the table.
3. Fold the cardboard to make a launcher.
4. Prop up the launcher.
5. Roll a marble across the board and down the paper at various speeds. Tilt the launcher to change the speed of rolling.



Questions to Think About

1. How does the direction of the path across the paper change each time the speed of the marble is changed?
2. Make up another experiment to prove what you have learned.

Learnings to Be Developed: When a particle of light enters a different medium at an angle, it changes both its speed and its direction.

Developing the Lesson: This topic can be introduced by discussing common examples of bending light—as with glasses of water. Develop the point that when light slows down, it is entering a denser medium, and its direction is now closer to the perpendicular. The opposite is true when light passes from a denser to a less dense medium.

The experiment on page 213 should reinforce this point. You can label the top half of the checkerboard "dense medium" and the bottom half "thinner medium" to clarify the experiment and its results. To create the opposite effect, you can place the checkerboard so that one half is lying flat and the other half is supported so that it is tipped upward from the center fold of the checkerboard. This form of the experiment would represent a particle of light passing from a less dense medium to a denser medium.

TEACHING SUGGESTIONS
(pp. 214–215)

Background: The answers to *Using What You Have Learned* are:

2. The light from the stars directly overhead enters the atmosphere exactly along the normal and, therefore, is not refracted. Starlight coming from any other angle is refracted as it enters the atmosphere.

You can see that fast-moving particles bend less than slow-moving ones. A bullet, for example, goes fairly straight to its target. The refraction of light, then, depends on its speed. Light bends more when it enters substances that slow it down. Since light behaves in this way, would you expect more refraction when it goes from empty space through glass or from air through glass?

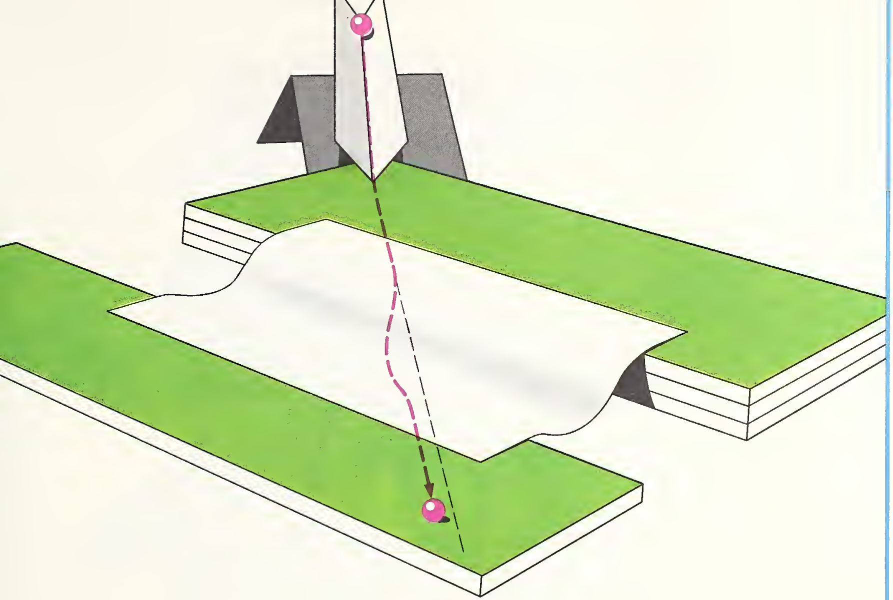
Although marbles are useful for demonstrating the particle idea of light, you must remember that marbles are not exactly like light. You could not demonstrate all the behaviors of particles of light with them. Imagine, for example, that two flashlights are turned on. The beam of one crosses the beam of the other. Each beam travels through the other as if it were not there. Now imagine two volleys of marbles crossing each other. The marbles would simply collide and scatter. You must think of light particles as being different. A light particle does not have a shape as definite as that of a marble.

Using What You Have Learned

1. Pictured on the next page is another way to study the bending of a particle's path. Tape a smooth piece of paper between two pads or long boards so that it forms a trough. One pad or board should be about two inches higher than the other. Make a launcher and prop it up. Roll marbles across the trough from your launcher. Roll them from the higher board to the lower. Roll them at different angles. See how the direction changes each time.

2. Astronomers know that stars are not where they seem to be unless they are directly overhead. Can you explain why stars overhead are seen in their correct positions while others are not?

3. Sir Isaac Newton was one of the world's greatest scientists. He used the particle idea to explain many behaviors of light. Find out about Newton's explanation of refraction.



4. Make a record of the path of a particle as it passes over different substances. Set up a single board with paper sloping gently off it to the table. Put a blank sheet of white paper on the level board and another on the table where the marble rolls off the paper slope. Place a sheet of carbon paper, carbon side down, on each of the sheets. Roll a heavy marble across the papers. Pick up the carbon papers and you will find a record of the marble's path.

Roll the marble at different speeds and compare the paths.

5. Put a penny in a shallow bowl. Step back until the penny is just hidden from your view by the side of the bowl. Now let a friend pour some water into the bowl without disturbing the penny. Do not move your head. The penny will come into view. Explain what happens.

4. In problem 1, the pupils will have discovered that the marble going over the trough is bent least when it enters along a line perpendicular to the trough. In problem 4, the same thing will, of course, remain true, but in this activity the pupils can make quantitative comparisons among paths of marbles shot at different speeds.

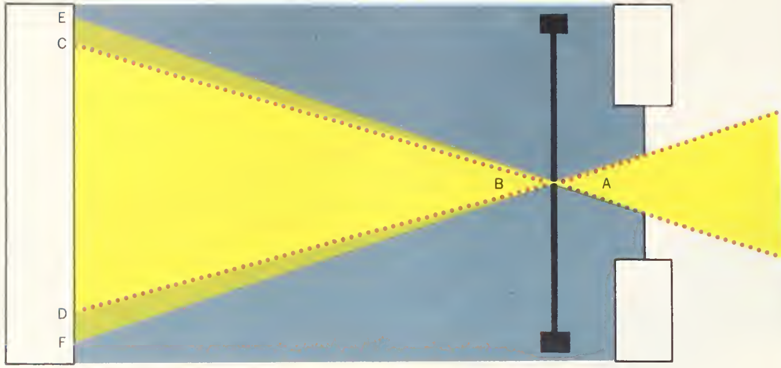
5. The explanation of why the penny comes into view is found on page 212. To understand this situation, the pupils might refer to the illustration of the girl looking at the fish. If the students imagine a barrier between the girl's eye and the actual position of the fish, they would then realize that the fish would not become visible until water was placed in the tank.

TEACHING SUGGESTIONS
(pp. 216–217)

● **LESSON:** What characteristics of light cannot be explained by the particle theory?

Background: This section introduces certain phenomena that cannot be explained on the basis of the particle theory of light—diffraction and interference. One way that the wave theory can be introduced is by performing the activities given on pages 216 and 217 and having the class discuss how the results can be accounted for if they assume that light consists of tiny particles of energy. Another method is to simply discuss these phenomena historically, mentioning the puzzlement these experiments aroused and how the results conflicted with the predominant particle theory. One thing to avoid is giving the impression that the wave theory has succeeded the particle theory. It has not. The phenomena already discussed and explained on the basis of the particle theory cannot be explained by the wave theory of light. One is left with two apparently contradictory explanations for all the observed characteristics of light.

Learnings to Be Developed: Diffraction and interference cannot be accounted for by the particle theory of light.



The Wave Idea of Light

Scientists have found the particle idea of light very useful. But there are some ways in which light behaves that the particle idea does not explain in a satisfactory way.

Problems Raised by the Particle Idea of Light

Imagine a beam of light entering a darkened room through a slit, shown by A in the diagram. This slit is blocked by a screen with a tiny hole in it, shown by B. The light is allowed to fall on a wall. Francesco Grimaldi (grih-MAHL-dih), an Italian scientist who lived in the 1600's, performed such an experiment. According to the particle idea, which represents light as traveling in straight lines, light should have been seen on the wall between points C and D only. Grimaldi found that light was seen as far as points E and F. He discovered that the light bent slightly as it passed the edges of the hole in the screen. The bending of light as it passes a sharp edge is called **diffraction** (dih-FRAK-shun).

Diffraction is different from refraction. Light does not pass from one substance to another. According to the particle idea, light should always travel in straight lines within a single substance. But in diffraction it bends around sharp edges.

The following activity demonstrates this behavior of light.

What Behavior of Light Is Not Explained by the Particle Theory?

What You Will Need

fluorescent light silk scarf

How You Can Find Out

1. Turn on the light in a far corner of a darkened room.
2. Hold the silk scarf at arm's length.
3. Look at the light through a tightly stretched section of the scarf.

Questions to Think About

1. Where is the light brightest?
2. Why doesn't the particle theory explain this behavior of light?

If light travels in a stream of particles, you would expect the light to pass in a steady stream through each tiny opening in the material. Instead, the light is brightest in the center of the scarf. Less bright patches of light extend from this center. The particle idea of light does not explain what is happening here.

The behaviors of light that cannot be explained in a satisfactory way by the particle idea have led scientists to the **wave theory of light.**

You are familiar with certain kinds of wave motion. For example, if you drop a pebble into a puddle, waves move out in all directions from the point where the pebble struck the water.

Developing the Lesson: The activities described on pages 216 and 217 are the crux of this lesson and both should be performed or carefully explained. The activity on page 216 resembles the experiment with a pinhole camera. Perhaps some of the pupils will be familiar with the fact that if you close the lens of a camera too much, the image will become fuzzy instead of continuing to increase in depth and sharpness. As for the observation described on page 217, the effect that is illustrated is interference. This effect is also shown on page 227. At the moment, the pupils do not have the background to appreciate why diffraction and interference effects occur. As the concept of wave motion is developed in succeeding pages, the *why* will become apparent.

ADDITIONAL ACTIVITIES:

There is another characteristic of light that is not explained by the particle theory. This is polarization. To demonstrate this effect, the pupils will need two pieces of very fine wire mesh, each about 2 inches square. Let them hold the squares parallel to each other and about 1 inch apart. Then let them rotate one of the squares as they look through both at a sheet of white paper. They will observe dark bands.

TEACHING SUGGESTIONS
(pp. 218—219)

● **LESSON:** How do waves travel?

Background: The point of this observation is to point out some of the characteristics of wave motion, to answer the question, "what is a wave?" Fundamentally, what this experiment shows is how a wave can travel the length of a rope without the rope's changing position. That is, every particle of the rope remains in its original position while the wave changes position continuously.

Learnings to Be Developed: The characteristics of wave motion can be used to explain some of the behaviors of light.

Developing the Lesson: The pupils are undoubtedly aware of waves and of their behavior in water. Begin the discussion by asking:

• *What do you know about the behavior of waves?*

Points to develop are that waves consist of *crests* and *troughs,* that they originate in a disturbance of some sort, and that the wave travels but the molecules of water remain in the same places. All these effects can be demonstrated by the length of rope described, and the pupils can see for themselves how a wave has the characteristics you have enumerated.

OBSERVATION

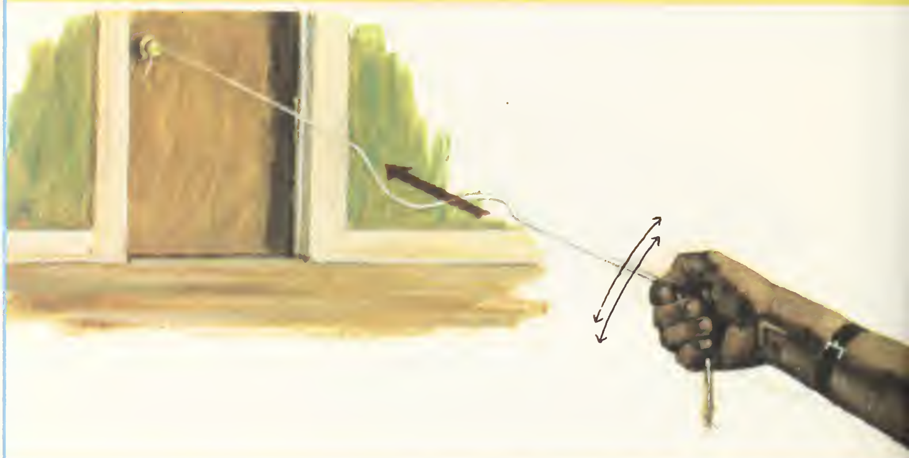
How Can You Produce Wave Motion?

What You Will Need

15-foot length of rope　　doorknob

How You Can Find Out

1. Tie the rope to the doorknob.
2. Hold the rope straight out, but leave a little slack.
3. Snap the rope sharply. Observe a wave travel along the rope.



Questions to Think About

1. Did the piece of rope held between your fingers travel? What travels is a pulse of energy called a wave. After the wave stops, all the parts of the rope are in their original positions. An important characteristic of wave motion is that substances in which a wave travels do not travel with the wave.
2. Can you hypothesize how wave motion might cause light to spread when passing through a silk scarf?

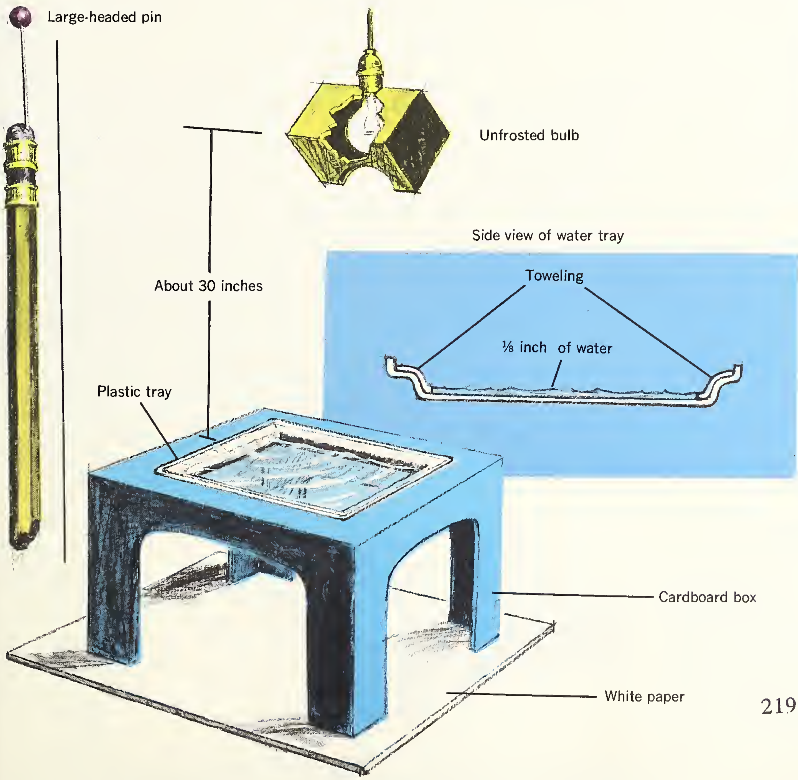
The pupils might also generate water waves in a shallow pan to observe the similarities between water waves and the waves along the rope. The fact that the water remains in the same position can be illustrated by dropping pieces of cork in the water. The cork will bob up and down but will not change position.

According to the wave idea, light travels out in waves in all directions from its source. This idea can be used to explain what happened in the activity with the silk scarf. But first you must learn more about wave motion.

Making a Ripple Tank

In many ways the behavior of water waves is like that of all waves. To study wave motion more fully, you will need a ripple tank. You will then be able to experiment with water waves.

Study the ripple tank shown in the diagram. When the light shines through the water and the plastic tray, shadows of any waves in the water will be formed on the surface beneath the tray. Shadows can be seen more clearly on white paper than on a floor or table top.



TEACHING SUGGESTIONS
(pp. 219–220)

● **LESSON:** How can we produce wave motion for study?

Background: Ripple tanks can be purchased from any of several science supply houses, but if there is time, the pupils should be encouraged to build their own as a class project. It is simple and the materials are easily enough found to enable the pupils to build ripple tanks at home. The most important point in using the ripple tank is that the light be bright and emanate from a point source. Frosted lamps are unsatisfactory. In performing the activities, be sure that the pupils understand that the motion of the waves and the motion of light are not identical. The water waves are only an analogy, just as the marbles used in previous demonstrations were not meant to be actual particles of light. The use of the ripple tank is only intended to help their understanding. In using the ripple tank, a small bit of experimentation will enable the students to generate any kind of wave they need. The pinhead generates circular waves; the dowel generates straight waves. Lay the dowel in the water, and tap it.

Learnings to Be Developed: We can study waves in water as an analogy to light waves.

Developing the Lesson: If you have an overhead projector, it can be used with good results, provided you get a clear plastic or glass tank for the platform. Do not put more than 1/2 inch of water in your tank. The procedure for illustrating wave action in water begins with step 10 on page 220, regardless of what form your apparatus takes.

Background: The answers to *Questions to Think About* on page 221 are:

1. Until they were reflected from the sides of the container, the waves moved out from the source (pinhead) in widening concentric circles.

2. Vary the speed of the pinhead vibrations and ask:

What changes do you notice in the waves? (The resulting change in frequency will give more waves for higher frequencies and fewer for lower ones. The waves will be closer together for high frequencies and farther apart for low frequencies.)

3. The ruler-induced waves will have a straight-line forward motion out from both sides of the source. Again, if your class is ready for it, ask the questions concerning velocity, number, and size of waves.

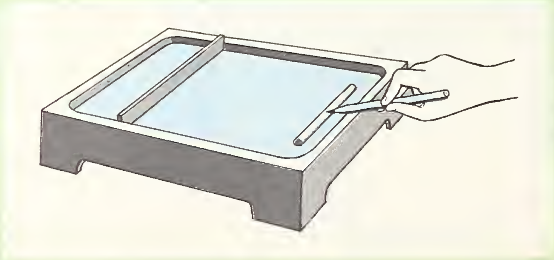
How Can Wave Motion Be Shown?

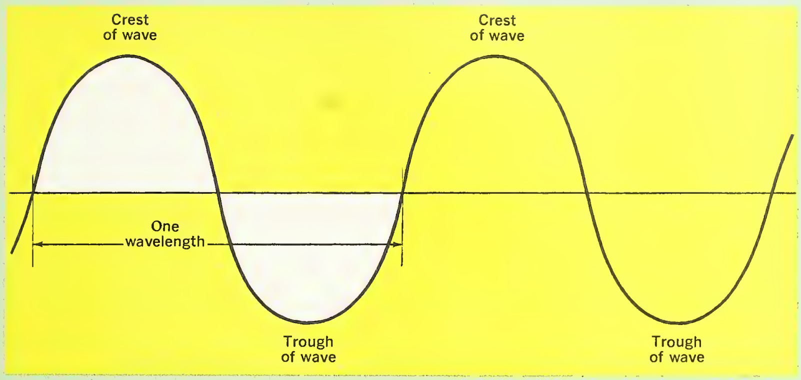
What You Will Need

large cardboard box	transparent plastic container (20″ x 10″ x 1½″)	pin
		pencil
unfrosted light bulb	white paper	paper towels
	level table	one-inch-thick wooden dowel
ruler	water	

How You Can Find Out

1. Cut large openings in the sides, top, and bottom of the box.
2. Spread a sheet of white paper on the table.
3. Put the box directly over the white paper.
4. Put paper towels along the edges of the plastic container.
5. Place the plastic container on top of the box.
6. Hang the light over the plastic container.
7. Fill the container with ⅛ inch of water.
8. Partially darken the room.
9. Turn on the light over the container.
10. Take the pencil with a pin stuck in the eraser and tap the water surface with the pinhead.
11. Adjust the light so that the shadows of waves show clearly on the paper.
12. Observe the wave shadows made by running your finger through the water in a straight line. This can also be done by using the dowel. Float the dowel at one end of the tank. Tap the dowel gently.





Questions to Think About

1. With the pinhead, waves move out in all directions, as light does. What form did the waves assume?
2. The **crest** is the high point of each wave. Each low point is called a **trough** (trawf). The pinhead waves move out in a circular pattern that is repeated again and again.
3. Put the edge of a ruler into the water. The ruler will disturb the water. Observe how the disturbance is passed along on the surface of the water. In what direction does it move out in relation to the ruler?

Reflection of Waves

We can use the wave idea of light to explain some of the same behaviors of light that we have explained by the particle idea. For example, we can explain reflection by using either the particle idea or the wave idea of light.

The next activity will explain how the wave model of light explains reflection. For this activity, you will use the ripple tank which you learned how to make on page 220.

TEACHING SUGGESTIONS
(pp. 221–222)

LESSON: How are waves reflected?

Background: The ripple tank is used here to indicate how the reflection of light can be explained on the basis of the wave theory. A ruler propped on its edge with a piece of plasticine makes an excellent obstacle for reflecting the waves. The obstacle will reflect waves very similar in appearance to the waves that strike it. Circular waves produce circular reflections; straight waves produce straight reflections.

Learnings to Be Developed: Both the straight-line motion of particles and wave motion can be reflected.

Developing the Lesson: Before the pupils conduct this observation, review briefly the facts concerning reflection already discussed on pages 202 through 209, but mainly the point that light is reflected from a surface at the same angle at which it strikes the surface. In conducting the observation the pupils can place sheets of paper underneath the ripple tank and draw lines corresponding to the angles at which the waves strike and reflect from different points on the obstacle. They should be equal when measured with a protractor.

Background: The answers to *Questions to Think About* (p. 222) are:

1. The reflections of the waves from the straight pulse are straight-line waves. From the circular waves you get an inversion of the arc in the opposite direction.

2. If light behaves in the manner of water waves, then the front of the wave can be reflected.

OBSERVATION

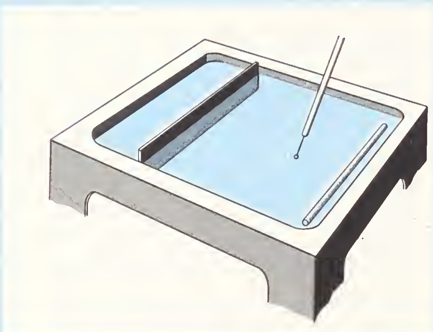
How Can the Wave Theory of Light Explain Reflection?

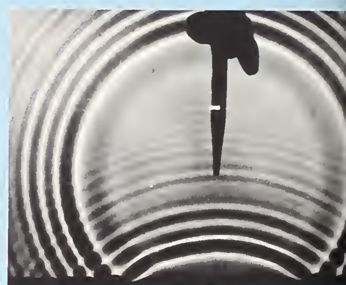
What You Will Need

ripple-tank apparatus	pinhead dowel	board (9¾″ x 2″ x ½″)

How You Can Find Out

1. Place the board across the tank, three quarters of the way from one end.
2. Produce circular waves with the pinhead.
3. Then produce straight waves with the dowel.
4. Observe what happens to these waves as they strike the obstacle.





Questions to Think About

1. How is the reflection of the straight pulse (made by the dowel) different from that of the circular pulse (made by the pinhead)?
2. How does the wave idea explain how light is reflected?

Refraction of Waves

Refraction, too, can be explained by the wave idea. The speed of a water wave depends on the depth of the water. Therefore, if you could change the depth in a section of your tank, you could make the waves change their speed.

Place a sheet of glass 10″ x 3″ in one section of the ripple tank. Produce waves with the dowel. Notice the waves that are made.

What happens to the waves as they pass over the glass? Why? Since light changes its speed as it goes from one substance to another, light waves are bent, or refracted, as they travel from air to water.

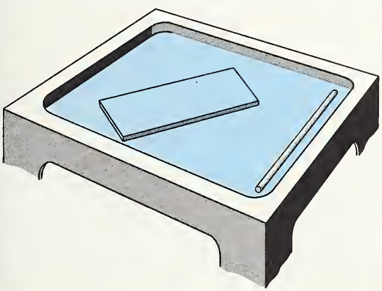
Crossing Beams of Light

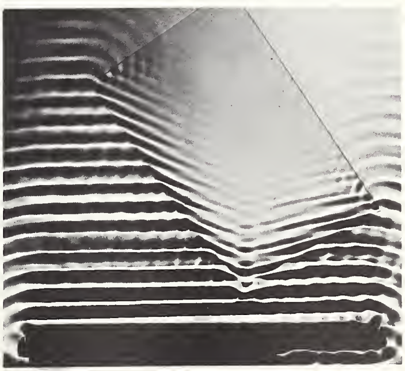
We discussed earlier what happens when we shine two flashlight beams across each other. Each beam travels through the other as though it were not there. We had some trouble explaining this behavior by the particle idea. Perhaps the wave idea fits this behavior better.

Waves can pass through each other without disturbing one another. Therefore the crossing of waves seems to be a better explanation than the crossing of streams of particles.

Diffraction of Waves

What happens in diffraction, or the bending of light as it passes a sharp edge? This bending is different from refraction. In refraction, the light, which is traveling in a straight line, bends to form an angle. The bending in diffraction might be described as a gentle curve. The particle idea, you remember, did not explain this behavior. According to the particle idea, what would you expect to happen when light passes a sharp edge?





TEACHING SUGGESTIONS
(pp. 223–224)

● **LESSON:** How do water waves behave when they pass a sharp edge?

Background: In this activity, the ripple tank is used to show how the refracting characteristics of light can be explained on the basis of wave motion. There is also an activity that shows how two waves can cross each other without interfering with each other, and an activity that shows how the waves exhibit the property of diffraction. For the refraction activity, the piece of glass should occupy 1/3 to 1/2 of the depth of the tank. That is, if the water is about 1/2 inch deep, the glass should be about 1/4 inch thick. The pupils should understand that decreasing the depth of the water makes the velocity of the waves increase, and that this is analogous to changing the slope of the checkerboard in the activities with the marble described previously. The diffraction activity shows one characteristic of light that can be explained on the basis of wave motion and not on the basis of particle motion. According to the particle theory, when light passes a sharp edge, there is a sharp shadow. Grimaldi's experiment showed this to be untrue. As shown in the diffraction activity, light actually bends slightly when it passes a sharp edge.

Learnings to Be Developed:

Light bends as it passes a sharp edge.

This bending is called diffraction.

Developing the Lesson: This is a demonstration lesson, and the procedure should depend heavily, as in all demonstrations, on the observational powers of the students.

Develop a series of questions similar to the following to emphasize all pertinent observational data.

- *Why are we using the ruler?* (A straight edge.)

Do not use a ruler with sloping edges.

- *Could we use other straight-edged objects?* (Of course.)
- *Describe the action of the water as it passes the sharp corner.*

Background: The answers to the *Questions to Think About* are:

1. The slight inward bending of the water waves should be noticed. This bending is diffraction.

2. Grimaldi's observations described a behavior of light analogous to the behavior of water waves in passing a sharp edge. There was a change in direction, or diffraction, that spread the light wave beyond the area in which it was expected.

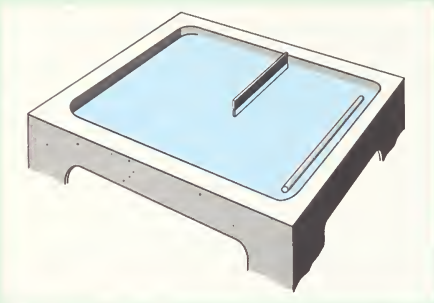
How Do Water Waves Behave When They Pass a Sharp Edge?

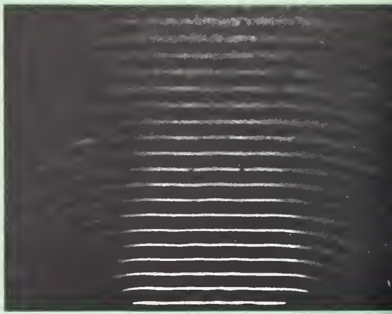
What You Will Need

ripple tank ruler wooden dowel

How You Can Find Out

1. Place the ruler in the tank.
2. Use the dowel to produce a wave.





Questions to Think About

1. What happens to the wave as it passes the edge of the ruler? The speed did not change, since the depth of the water was not changed. The change that did occur was due to diffraction, not refraction. In diffraction the waves do not bend so sharply. Light waves are also diffracted after passing a sharp edge.
2. Look against the picture on page 216 and the description of Francesco Grimaldi's experiment on page 216. Can you explain now what Grimaldi observed?

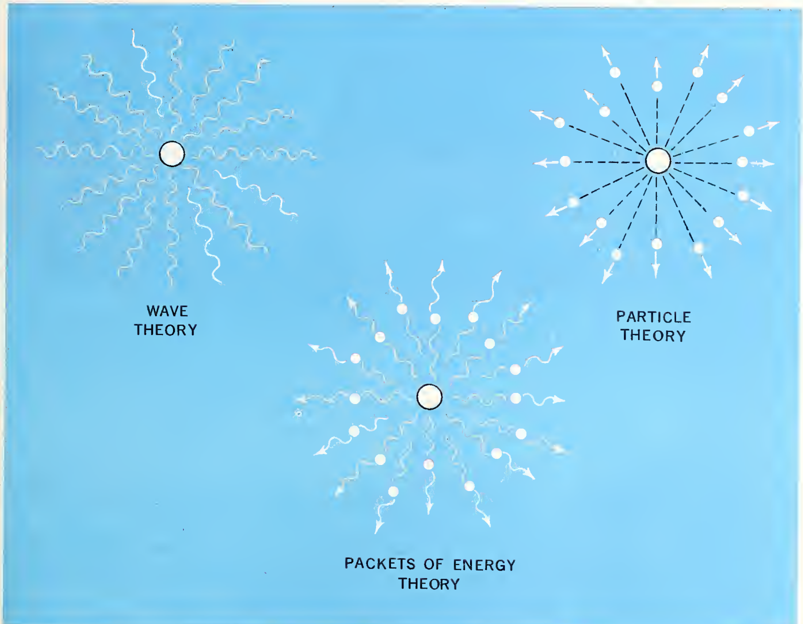
Wave Theory or Particle Theory?

Diffraction, then, is one behavior of light that can be explained by the wave idea and not by the particle idea. The wave idea is useful, too, in explaining other behaviors that you will learn about later on in your study of light. But it does not explain all the behaviors of light.

Both the particle idea and the wave idea are useful, but neither by itself is entirely satisfactory.

Today, scientists think that the most satisfactory explanation is a combination of both. They think of light as little packets of energy behaving like waves. As you go on in science, you will learn more about these packets of energy and how they move from place to place in a wave motion.

Is light a kind of wave motion, as shown on the left, or is it particles in motion, as on the right? Scientists think it may be a combination of both, as in the center.



TEACHING SUGGESTIONS
(p. 225)

LESSON: Does either the wave theory or the particle theory alone explain all the observable properties of light?

Background: This page summarizes the contents of this unit. The main impression that the pupils should be left with is that neither the wave theory nor the particle theory can explain entirely all the observed properties of light, and that some sort of combination of the two theories is necessary. According to quantum theory, light consists of discrete particles called *photons,* which move individually with a wave motion. Statistically, when a sufficient number of photons strike a surface, they create the effect of a wave motion because of the average way in which they strike the surface.

Learnings to Be Developed: A combination of both theories is necessary to explain all the observable properties of light.

Developing the Lesson: The pupils can summarize what each theory explains best and what each theory cannot account for.

TEACHING SUGGESTIONS
(pp. 226–227)

Background: The answers for *Using What You Have Learned* are:

1. The waves move out from the point at which the marble strikes the water. The pieces of cork bob up and down; they do not move along with the wave.

2. The first marble strikes and produces a wave impulse, causing the last marble to shoot out.

3. The sun's rays are refracted over the horizon by the earth's atmosphere. The sun has actually disappeared behind the horizon before its rays disappear from view.

5. Sir Isaac Newton was one of the first men to separate sunlight into the colors of the rainbow by using a triangular prism. Scientists refer to the "rainbow" as a *spectrum*.

6. The bands of light and dark produced on the screen are a result of *interference*. This phenomenon can be explained easily by the wave theory of light.

Notice in the diagram at the bottom of page 227 that the situation is similar to generating circular waves very close to one another. When crest meets crest, a band of light is reinforced, and the light

Using What You Have Learned

1. Show that the substance in which a wave travels does not move along with the wave. Put about two inches of water in a large basin. Float small pieces of cork or balsa wood in the basin. Drop a marble or pebble in the exact center of the basin and observe the wave motion and the effect on the bits of cork or balsa. From what point do the waves move out? Do the pieces of cork or balsa move along the surface? How do they move?

2. Here is another way to show that waves do not carry along the substance in which they travel. Line up ten marbles between two rulers as you see in the diagram. Shoot a marble against the first marble in line. What happens?

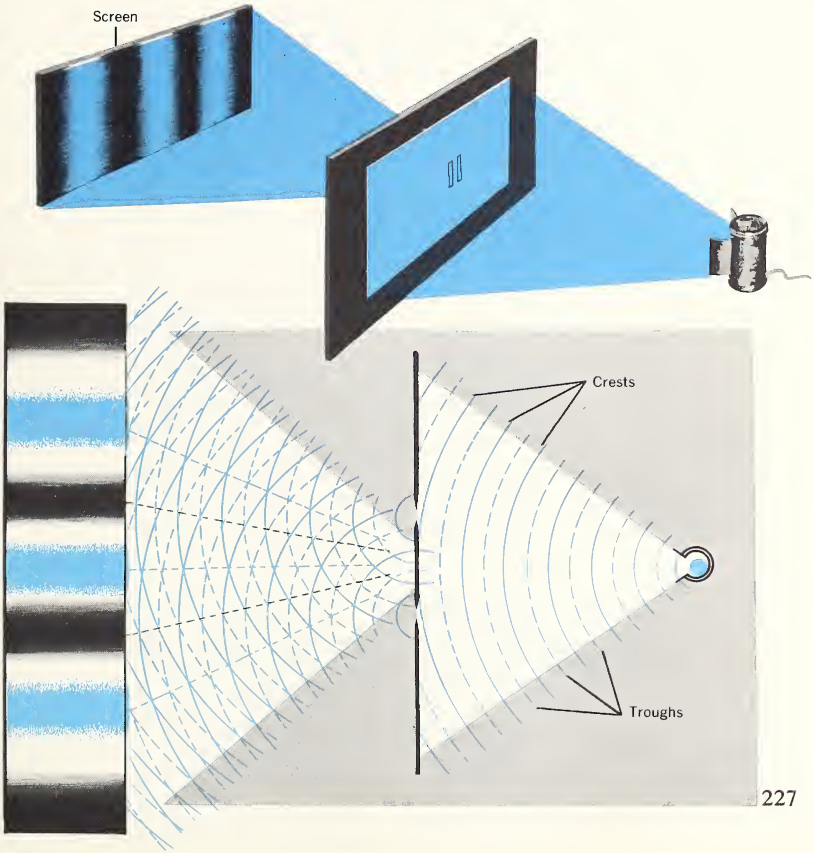
3. After the sun has sunk below the horizon, we can still see it for a few minutes. Can you explain why?

4. Find out about Thomas Young and Christian Huygens. Read about some of their important scientific discoveries.

5. Sir Isaac Newton did a famous experiment to show that white light is made up of many colors and that light of a single color is not. Find out about this experiment.

Groups of students should prepare color wheels. Cut 3" or 4" cardboard disks and divide them into three sections, each section colored with a primary color. Spin the wheels on a pencil point inserted at the center. When the colors are balanced you should perceive a grayish white while the disk is spinning.

6. Imagine that light from a single source is permitted to enter through two slits as shown in the upper section of the diagram below. What would you expect to appear on the screen according to the particle theory of light? The screen shows what actually does happen. The lower part of the drawing shows how the wave theory explains what happens. Can you explain the diagram?



appears brighter. When crest meets trough, however, the waves cancel each other, and darkness results.

○ **ADDITIONAL ACTIVITIES:**

The pupils can generate circular waves close to each other in the ripple tank and see if they can detect the interference patterns.

Place a transparent scale ruler under your ripple tank and take quantitative measurements of the projected waves. Count them in some unit of time (e.g., minutes). Pose the question, "Can we tell how fast the water waves are traveling?" Challenge your more able pupils to work out a relationship between velocity, frequency (number of waves per minute), and wavelength.

Speed = frequency × wavelength.

While the spectrum and colors did not come in for serious study in our unit, your class might like to explore the subject. They are probably familiar with the triangular prism's ability to break up light into colors. Explore the use of *replica diffraction gratings* for the same purpose. Results are more spectacular and the grating is less expensive.

TEACHING SUGGESTIONS
(pp. 228–229)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What Have You Learned: This is a summary of the entire unit, with new words in boldface type.

Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390-393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

WHAT YOU KNOW ABOUT

The Nature of Light

What You Have Learned

There are two different theories used to explain the nature of light. These are the **particle theory** and the **wave theory.** Neither theory alone completely explains the behavior of light. The most satisfactory explanation is a combination of both theories.

The particle theory of light says that light consists of tiny particles of energy called **corpuscles.** The wave theory of light says that light consists of waves that travel from a source.

When light strikes an object, some light is reflected. We see objects because the light is reflected into our eyes.

Light travels at different speeds through different materials. When light passes from one material into another, it changes speed. The change in speed causes the light to bend. This bending is called **refraction.**

When light passes a sharp edge, it is also bent. This kind of bending is called **diffraction.** Both the particle theory and the wave theory can explain reflection and refraction of light. The wave theory can also explain diffraction, but the particle theory cannot. However, the particle theory can explain how light can travel through empty space, and the wave theory cannot.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

crest	particle theory	trough
diffraction	refraction	wave theory

Which Theory?

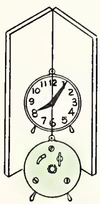
Tell which theory, **A** or **B**, describes each behavior of light listed below. Write the numbers **1** to **6**, and next to each, **A** or **B**.

A. Particle theory **B.** Wave theory

1. Light is made up of tiny particles that move rapidly.
2. Light bends slightly as it passes a sharp edge.
3. Light can travel through empty space.
4. Light forms an upside-down image in the pinhole camera.
5. Light usually travels in straight lines.
6. Light travels out in all directions from its source.

What Is Happening?

Explain what is happening in each of the pictures below.

1


2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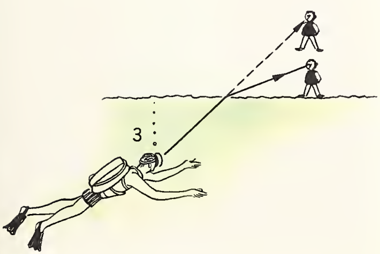

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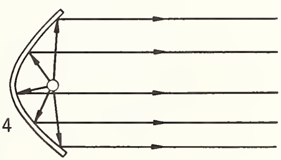


Which Theory?

1. A 4. A
2. B 5. A
3. A 6. B

What Is Happening?

1. The image of the clock reflected in the mirrors is not reversed. There is a double reflection to arrange the image into its usual and expected position. Look at a clock in a single plane mirror.

2. The image of the pencil within the water appears to be broken because of the effect of refraction.

3. The skin diver looking up and out of the water thinks the boy standing on the shore is higher than he really is. The boy on the shore, on the other hand, thinks the skin diver is closer than he really is.

4. The parabolic surface of the light reflector reflects the light so that it travels in parallel paths.

TEACHING SUGGESTIONS
(pp. 230–231)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

What Are the Words?

1. Corpuscles
2. Trough
3. Diffraction
4. Light
5. Wave theory
6. Crest
7. Refraction

You Can Read: In addition to the general texts on optics already recommended, the following books may be helpful.

The Magic of Rays, by J. Dogigli (Knopf, 1960). *Michelson and the Speed of Light,* by B. Jaffe (Anchor, 1960). *Rays: Visible and Invisible,* by F. Reinfeld (Sterling, 1958). *Light: Visible and Invisible,* by E. Ruechardt (University of Michigan, 1958).

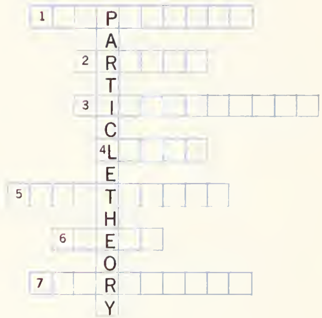
YOU CAN LEARN MORE ABOUT

The Nature of Light

What Are the Words?

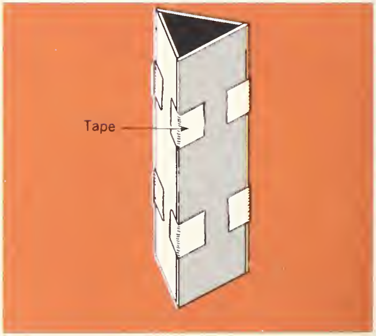
Write the words in your notebook.

1. Newton's word for light particles.
2. The lowest point of a wave.
3. The bending of light as it passes a sharp edge.
4. A form of energy that can be described only in terms of its behavior.
5. The theory that explains diffraction.
6. The highest point of a wave.
7. The bending of light as it passes from one substance into another.



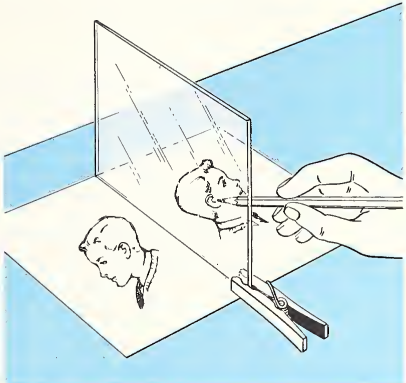
You Can Make a Kaleidoscope

A kaleidoscope is a simple device that can make many images. You will need two mirrors and a piece of cardboard, all exactly the same size and shape. Use rubber bands or tape to hold together the three pieces. Tape a piece of waxed paper over one end. Place a pane of glass on two wooden blocks. Put small pieces of colored paper on the glass. Set the kaleidoscope over the colored pieces of paper. Tap the glass as you look into the kaleidoscope. How does it work?



You Can Copy Drawings by Reflection

You will need a piece of clear glass and a wooden clothespin. Use the clothespin to hold the glass vertically on a table. Place a drawing you wish to copy on one side of the glass and a sheet of white paper on the other side. Look through the glass at the white paper and draw over the reflection you see of the drawing. How does the copy compare with the original drawing? Why does the glass have to be held vertically?



You Can Read

1. *Experiments with Light*, by Nelson F. Beeler and Franklyn M. Branley. Many experiments are suggested to show the nature of light and the working of lenses.
2. *Light and Color*, by Frederick Healey. Discusses the physical properties of light and suggests experiments.
3. *The First Book of Light*, by George R. Harrison. A good general book about light and its properties.
4. *The Wonder of Light*, by Hy Ruchlis. Fascinating photographs and comparisons make this an interesting book.
5. *Understanding Light: The Science of Visible and Invisible Rays*, by Beulah Tannenbaum and Myra Stillman. Many topics as well as the work of various scientists are included.

Additional Readings:

Color in Your Life, by Irving Adler (Day, 1962). Basic structure and characteristics of light; complex phenomena such as polarization and the Doppler effect; color in nature.

Prisms and Lenses, by Jerome S. Meyer (World, 1959). Introduction to the science of optics; discussions of dispersion, reflection, and refraction.

Films:

Demonstrations with Light (12 min., color, Moody Institute of Science). Specially designed lab equipment is used to illustrate the various theories of light—nature, speed, means of propagation. Persistence of vision is illustrated and explained. Good motivation for physical sciences is provided by questions concerning light as a medium for sound transmission.

The Science of Light (11 min., color, Churchill Films).

Color and Light: An Introduction (11 min., color, Coronet).

Light: Lenses and Optical Instruments (13½ min., color, Coronet).

Light: Reflection (13½ min., color, Coronet).

Light: Refraction (13½ min., color, Coronet).

NOTES:

Use this space for any additional teaching suggestions you may have.

Do You Remember?

Through the centuries, systems of measurement have been devised and discarded, until the systems we now use were developed. Measurement is vital to almost all scientific exploration.

Units of measurement that everyone agrees upon are called *standard units.* There are two systems of standard units. One is the *English system,* in which the inch, foot, yard, and mile measure length, the ounce and pound measure weight, and degrees *Fahrenheit* measure temperature. The other system is the *metric system,* in which the centimeter, meter, and kilometer measure length, the gram and kilogram measure the mass of objects, and degrees *Centigrade* measure temperature.

Often, scientists want to measure how much material, or *matter,* makes up an object. They use a unit that measures the *mass.* Mass is the amount of matter in an object.

Scientists use *formulas* and *graphs* to show relationships among such things as speed, time, and distance.

Velocity, which is how fast an object travels in a certain direction, is a quantity that can be represented as a *vector.* A vector quantity has both size and direction.

Measurement is important in understanding the relationship between heat and molecules. The molecules of a substance always move at different speeds. Temperature measures average speed of molecules. Heat is the effect of movement of all molecules in a substance. Molecules of one kind of matter move to an area of fewer such molecules. This is called *diffusion.*

To measure motion of an object, you must measure its speed. You need a device such as a pendulum to measure equal *time intervals,* and a method for measuring distances traveled. An object at rest does not move if forces on it are equal in size and are from opposite directions. These forces are *balanced forces.* To move an object, the balance of forces must be upset. *Frictional forces* may stop an object. Isaac Newton said that if

no other force is exerted on an object, the object will remain at rest or continue to move in a straight line at a constant speed. This statement is known as the *First Law of Motion*. Newton also worked out the mathematical relationship among force, mass, and *acceleration*. This relationship, called the *Second Law of Motion*, says that if you double the force on a certain mass, the acceleration doubles. If you use the same force on a mass twice as great as another mass, the acceleration of the greater mass is only half that of the smaller mass. To get the same acceleration by a mass twice as great as another, you must exert twice as much force as on the smaller mass.

All objects in the universe are composed of matter. Wherever matter exists in any form, electricity also exists. In the *atom*, the nucleus electrically attracts the *electrons*. The electrons also electrically attract the nucleus. But electrons repel other electrons. Thus, there are two kinds of electric forces—attraction and repulsion. Electrons and *protons* are particles of matter that scientists believe cannot be divided further. They are called *elementary particles*. The charges these particles carry cannot be reduced. These are called *elementary charges*. A current of moving electrons generates a *magnetic force*.

Measurement is used in astronomy to find distances to stars. Astronomers use *parallax* to measure distances to objects in space. *Similar triangles* help scientists to measure the sizes of the planets, sun, and moon. We get information about objects in space from light they give off.

Scientists think of light as little packets of energy behaving like waves. Light can travel through empty space. Light usually travels in straight lines. When light strikes an object, some of the light is reflected. The bending of light when it enters a different substance is called *refraction*. The bending of light as it passes a sharp edge is called *diffraction*.

NOTES:

Use this space for any additional teaching suggestions you may have.

KEY CONCEPTS

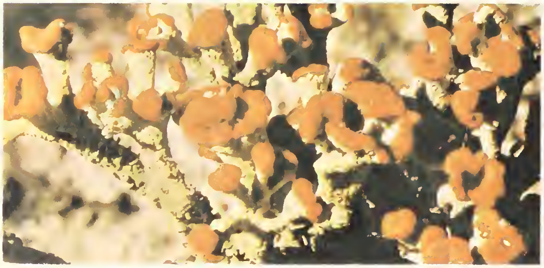
Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

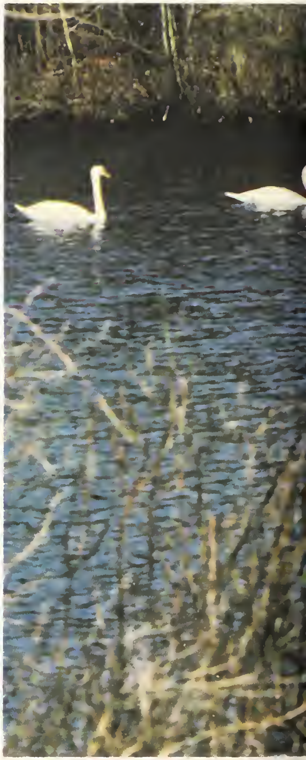
Key Concept 2. Lawful change is characteristic of events in the natural environment; although living things tend to produce living things like themselves, over millions of years the earth and living things on the earth have changed, and diversified forms of life have evolved.

Key Concept 3. To find order in the natural environment, the scientist seeks basic units that can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.

Key Concept 5. The motion of particles helps to explain such phenomena as heat, light, electricity, magnetism, and chemical change.

Key Concept 6. There is a basic tendency toward stability or equilibrium in the universe; thus, energy and matter may be transformed, but the sum total of matter and energy is conserved.





7

Other concepts appear under "Learnings to Be Developed" in each lesson found in the Teaching Suggestions.

Life on the Earth

Materials, Energy, and Living Things

How Plants and Animals Survive

Conserving Our Resources

Key Concept 7. When equilibrium is upset in organism-environment interactions, regulatory mechanisms go to work to restore equilibrium.

Key Concept 8. There is a relationship between structure and function; the structure of parts of living organisms determines the function of those parts.

Key Concept 10. Man has changed and continues to change the natural environment; because he is often ignorant of long-range consequences, his actions may have harmful effects for himself and other living organisms.

CONCEPTS:

1. Green plants link the earth's elements, the sun's energy, and living things.
2. Plants and animals are adapted to the environments where found.

PROCESSES:

- Questioning—Page 240.
- Observing—243, 245, 247, 254, 263, 294, 295.
- Comparing—241, 242, 243, 245, 247, 254, 294, 295.
- Selecting—246, 248, 258, 260, 262, 265, 268, 272, 294, 295.
- Demonstrating—243, 245, 246, 263, 294, 295.
- Explaining—239, 241, 242, 246, 247, 254, 255, 256, 262, 263, 264, 265, 268, 294, 295.
- Hypothesizing—243, 252.

TEACHING SUGGESTIONS
(pp. 236–238)

LESSON: What is needed to produce motion or change?

Learnings to Be Developed: Energy is needed to produce motion or change.

Developing the Lesson: Since the energy of photosynthesis is your point of departure, it might be well to introduce this unit by a discussion of the energy needs and the sources of energy of nonliving things. Ask:

- *What is the source of energy for a wrist watch? A car? An electric generator plant? A jet plane? A rocket?* (The usual wrist watch uses the energy of a coiled spring. A car uses the stored energy in petroleum products. A hydroelectric plant uses the energy of falling water or the burning of hydrocarbons [coal or oil]. A jet plane uses petroleum products. Rockets use a variety of chemical fuels, both solid and liquid.)

Challenge pupils to provide examples of change or motion that do *not* need energy. There are no common examples. Even the planets had energy imparted to them originally.

All the materials found in living things are also found in the earth. Living things are dependent on many of the earth's materials. The energy that a living thing obtains from its food is energy that comes from the sun. Living things cannot create new energy; they can only change energy into other forms.

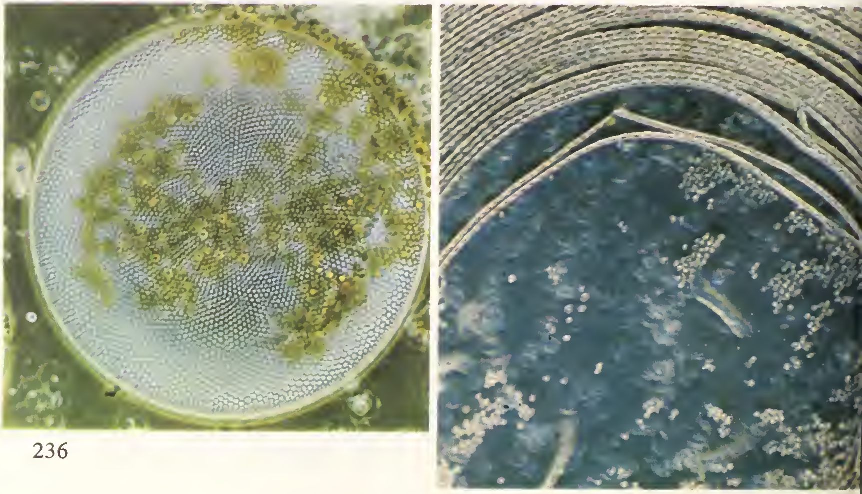
Materials, Energy, and Living Things

Although living things are made of the same materials as those found in the earth, they differ in many ways from rocks and water and sunshine. You will now learn of the relationship among the elements from the earth, the energy of the sun, and living things.

Green Plants—The Starters

All living things are dependent on other living things—green plants. Green plants link the earth's elements, the sun's energy, and living things. They capture and use the energy of the sun in the process called *photosynthesis*.

How do the one-celled plants shown here serve as links among the earth's elements, the sun's energy, and living things?

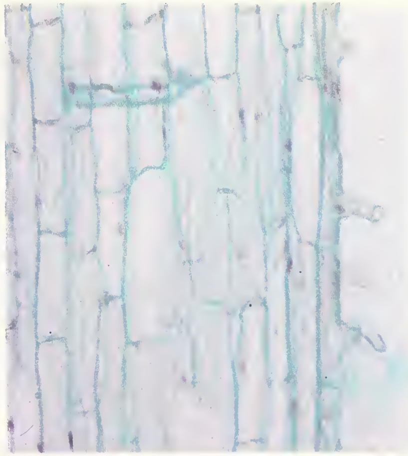


In this process, the green plant can be compared to a factory. Raw materials are taken in by the plant to make products that, in turn, are used by living things.

Taking in raw materials and processing them requires a transportation system. A factory's transportation system consists of trucks, railroad cars, airplanes, moving belts, dollies, and elevators. Green plants, especially those that live on land, also require a transportation system. Of what does this system consist?

The Transportation System of Plants

When we think of plants, we usually think of those that grow in forests, fields, and gardens. Actually, these are a very small part of all the green plants on the earth. About 90 per cent of the green plants on the earth are found in the oceans. Most of these are single-celled plants such as those shown in the picture on page 236. All green plants need water, carbon dioxide, oxygen, and minerals. Plants that live in water have little difficulty in getting the materials they need. Where do they get their water? Where do they get carbon dioxide, oxygen, and minerals? Land plants, however, have had to develop a transportation system for obtaining water, carbon dioxide, oxygen, and minerals from their environment.



Can you describe the way in which water enters the roots of a plant from the soil?

Water containing dissolved minerals is taken from the soil. Most of the water is absorbed by the very small parts of roots called *root hairs*. You can see these root hairs in the photograph above. Water that is taken up by root hairs moves across the root until it reaches a bundle of very fine tubes. The water then moves up these tubes, through the roots and stem, to the leaves.

If you hold a green leaf up to the light, you can see a network of lines. These are called *veins*. The veins are bundles of water-carrying tubes in the leaf.

Using a sharp razor blade and a little care, you can peel the epidermis from most common leaves. It is interesting to peel off the lower and upper epidermis and compare them under a microscope.

○ **ADDITIONAL ACTIVITIES:**

A week previous to the lesson some lima beans could be grown on moist blotters. There should be enough growth in a week to be able to see the tiny root hairs near the tips of the developing root with a hand lens or, better, with a microscope.

If an aquarium is available, look for some green "scum" on the sides of the tank, and carefully remove some of it to a microscope slide. Try to have pupils find one-celled plants similar to those pictured on page 236.

If anyone in the class has a diatomaceous-earth filter from a home swimming pool or fish tank filter, examine a few "grains" under a microscope. This earth is really composed of the dead remains of the diatoms or the capsules in which the plants once lived. The shapes of diatoms vary considerably.

Have the pupils examine a small piece of blotting paper, tear it apart, and notice the tiny fibers. Blot a few drops of water colored with ink. Have them supply you with possible explanations of the water's rise in the blotter. This capillary action is a partial explanation of the way water rises in the veins of plants.

TEACHING SUGGESTIONS
(pp. 238–240)

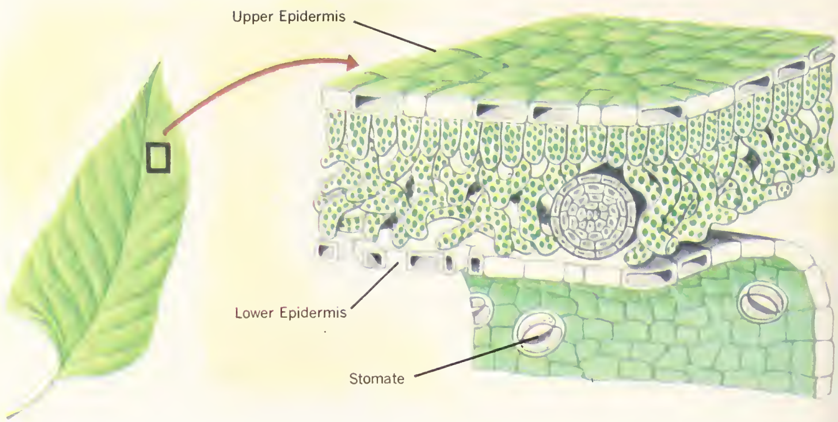
LESSON: What is chlorophyll?

Background: The word *chlorophyll* means "lover of green." It is a strange name, because chlorophyll does not utilize the green coloring at all. Chlorophyll absorbs red, blue-violet, and other colors but readily allows green wavelengths to pass through or bounce off. Remember, we see a color that is reflected by a pigment. We do not see the wavelengths that are absorbed.

Experiment with colored cellophane to filter out different wavelengths of light. Wrap several potted house plants in colored cellophane; some in clear cellophane. Results should appear in a week.

There are several pigments in green leaves besides chlorophyll. Chlorophyll *a* is blue-green, chlorophyll *b* is yellow-green, and carotene-related pigments are red and orange. When conditions for chlorophyll are not optimum (as in the fall and winter), it deteriorates, and the yellow, reds, and oranges are more noticeable. Science is interested in all these pigments, because they all take part in the energy-storing process.

Learnings to Be Developed: Green plants contain chlorophyll.



What are the small round bodies seen within the cells of the green leaf? How does carbon dioxide enter the leaf? How does oxygen leave the leaf?

Plant some radish seeds. As soon as they begin to sprout, examine their roots with a magnifying glass. Note how very many root hairs there are on one radish root. Remember, it is through the root hairs that water is absorbed by the plant.

Now look at the diagram of the leaf. The covering tissue of the leaf is made of cells tightly packed together. This tissue is called the **epidermis** (ep-uh-DER-miss). Between the cells that make up the epidermis are the cells in which photosynthesis takes place. Can you tell where water passes into the leaf from the veins? Can you tell where carbon dioxide enters the leaf from the air? You will see that there are very small openings in the lower layer of cells. These openings are called **stomata** (STOH-muh-tuh). Carbon dioxide enters the leaf through the stomata.

Capturing the Sun's Energy

How does the green plant use raw materials to make food? First, it splits molecules of water into hydrogen and oxygen. The oxygen is released. The hydrogen is combined with carbon dioxide to form sugar. Work is involved in taking molecules apart and putting them together again. It takes energy to do work.

The Sugar Molecule and Energy

There are several different kinds of sugar. The molecules of each kind of sugar contain the same elements—carbon, hydrogen, and oxygen. The simplest sugar is *glucose*. Its chemical formula is $C_6H_{12}O_6$. The sugar that green plants produce by photosynthesis is glucose. Plants make other sugars from glucose. They also make starch, fats, proteins, and other plant materials from glucose. Plants do not need light to make other materials from glucose, but they do need energy. Since energy cannot be created, where do they get it?

Light energy from the sun is used by the green plants to put together carbon, hydrogen, and oxygen to make a molecule of glucose. Glucose, a form of sugar, is the product of photosynthesis. The energy used is stored in the molecule of glucose. By chemical means the plant can release this stored energy from a glucose molecule and use it to do many things. Remember that the energy from the sugar molecule originally was light energy. By the process of photosynthesis, light energy was changed by the green plant into chemical energy in the form of glucose. All living things depend on green plants to do this.

It was only a little more than one hundred years ago that biologists determined that green plants use water and carbon dioxide to make sugar. Though they knew that green plants need light to do this work, they did not know how they use it. Since that time many scientists have worked on the problem. Today we know much more about how photosynthesis takes place in green plants, but there are still some questions that have not been answered. Scientists in many parts of the world continue the search for more information about photosynthesis.

Chlorophyll

You know that the activities of living things take place in cells. Green plants such as those shown on page 236 are single-celled. Each cell contains the green material *chlorophyll* (KLOR-uh-fil). Chlorophyll makes it possible for a cell to change carbon dioxide and water into sugar by using light as energy.

But what is chlorophyll? This is a question that **biochemists** (by-oh-KEM-ists) have tried to answer for a long time. Biochemists are scientists who study the chemical processes that take place in living things. They have found that there are several different kinds of chlorophyll. Some are more common in one type of green plant than in others.

Chlorophyll is a complicated compound. Its molecules are made up of several elements. The chemical formula for one kind of chlorophyll, called

Alcohol, or even nail polish remover, may be used in place of the acetone if your need is small.

Developing the Lesson: Chlorophyll can be extracted from leaves and studied. Get a few leaves of spinach (or another green-leafed plant) and crush them in an electric blender. When they are in a pulp state, pour some acetone into the container and allow the leaves to soak for a few minutes; then turn on the blender again. Allow the leaves to settle for a short time, and then pour off the liquid. Collect the green fluid in a large test tube or glass bottle and cork it for the pupil's use.

Depending on the amount of liquid collected, provide teams of students with a test tube each. Into each tube pour about 1/2 inch of the green liquid that contains the coloring matter of the leaves. Each tube should be provided with a strip of white blotting paper or else filter paper.

Have the teams place the end of the strip of paper into the liquid and let it remain suspended in the tube while the liquid creeps up the strip. If the activity is successful, you should be able to notice at the edges of the strip, near the top, some gradation of color from deep green (lower end) to lighter green (middle) to a yellow green (near the top). You have separated some of the pigments from the leaf. The yellow fringes are an indication of the pigment *carotene*.

TEACHING SUGGESTIONS
(p. 240)

● **LESSON:** How do living things use oxygen from the air?

Background: Oxygen atoms are needed by all living things. Oxygen atoms combined with carbon and hydrogen are part of sugars and starches. Oxygen atoms combined with hydrogen produce water, which living things need to dissolve foods. Oxygen atoms combined with carbon yield carbon dioxide, which animals find poisonous, but plants find necessary. The same oxygen atom may find itself in many different compounds in the course of a single day.

Learnings to Be Developed:

One of the products of photosynthesis is oxygen.

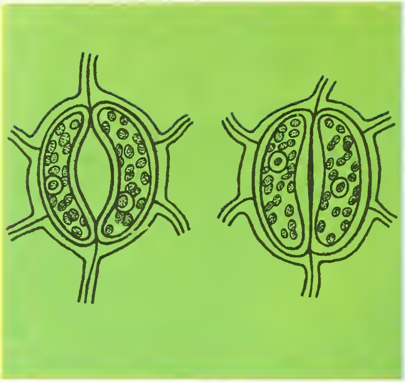
All things depend on green plants for oxygen.

Developing the Lesson: Have a discussion centered around the oxygen atom. Trace all the possible ways it could be transformed from a molecule of one substance to a molecule of another and carried in and out of living things.

Discuss answers to the last question on page 240. Basically, the answer is that animals *could* not appear until green plants were releasing oxygen into the earth's atmosphere.

chlorophyll *a*, is $C_{55}H_{72}O_5N_4Mg$. What different elements make up this molecule? How many atoms of each element are in the molecule of chlorophyll *a*? What is the total number of atoms in the molecule?

The picture at the right shows the cells in a green leaf where photosynthesis takes place. The small green parts of the cells are called **chloroplasts** (KLOR-uh-plasts). Chloroplasts make chlorophyll from materials in the cell. These materials contain atoms of carbon, hydrogen, oxygen, nitrogen, and magnesium.



A close-up of chloroplasts in a green leaf.

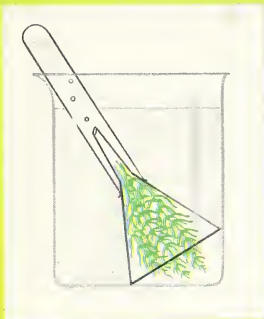
Materials from Green Plants

Animals and other plants depend on green plants for more than energy. The materials that green plants produce also contain the elements that living things need to build cells and tissues. These elements include carbon (C), hydrogen (H), oxygen (O), phosphorus (P), potassium (K), nitrogen (N), sulfur (S), calcium (Ca), iron (Fe), and magnesium (Mg). Green plants obtain some of these elements from the air, some from water, and some from rocks and soil.

Oxygen from Green Plants

You know that all living things use oxygen from the air. They use the oxygen to release energy from food molecules. In this process, oxygen combines with carbon in the food to form carbon dioxide. When oxygen is united with carbon in a molecule of carbon dioxide, it cannot be used by animals. But green plants use carbon dioxide as one of the raw materials in photosynthesis. One of the products of photosynthesis is oxygen. As green plants carry on photosynthesis, oxygen is returned to the air. All of the oxygen in the air is a result of the process of photosynthesis. If it were not for green plants, there would be no oxygen in the air. All living things depend on green plants for oxygen. Can you tell why scientists believe that green plants were among the first living things to appear on the earth?

How Can Oxygen Be Collected from a Green Plant?



What You Will Need

large jar or beaker
glass funnel
test tube
electric hot plate
kettle or pan
5 to 10 sprigs of fresh elodea plant
⅓ teaspoon baking soda
1 quart of water from an aquarium

How You Can Find Out

1. Add ⅓ teaspoon of baking soda to 1 quart of boiled aquarium water and stir until the soda is completely dissolved. This will supply the carbon dioxide that the elodea plants need to carry on photosynthesis.
2. Arrange the elodea plants under the funnel and test tube as shown in the drawing.
3. Place the setup in the sun and observe bubbles of oxygen rise into the test tube. It may take as long as three hours for this process to begin. As bubbles rise in the test tube, water is forced out of it.

Questions to Think About

1. Why is the setup placed in sunlight?
2. What happens when you shade it from the sun?
3. How can you be sure that the gas that you have collected in the test tube is oxygen?

In order to provide a control for this activity, set up a second experiment, identical in all respects but one. Place this control in a closet, or cover it entirely with a cardboard box, so that no light will enter. Comparison with the initial results should be convincing evidence of the need for light energy.

TEACHING SUGGESTIONS
(p. 241)

● **LESSON:** How can oxygen be collected from a green plant?

Learnings to Be Developed: Photosynthesis releases oxygen to the surroundings.

Developing the Lesson: Before actually performing the activity, have the class discuss the steps.

- *Why do you use aquarium water?* (Contains the usual environmental condition for the elodea.)
- *Should the test tube be filled with water before starting? Why?* (Yes. Otherwise the tube would contain atmospheric gases during collection of oxygen.)

Background: Answers to the *Questions to Think About* are:

1. To provide an energy source.

2. Depending on the amount of light, the production of bubbles should slow down.

3. The test for oxygen: Insert a glowing splint into tube—splint bursts into flame.

Note: Do not use *baking powder;* it contains an acid that releases CO_2 rapidly in water. This could lead to a collection of CO_2 and O_2. Sodium bicarbonate, bicarbonate of soda and baking soda are names for the same substance.

TEACHING SUGGESTIONS
(pp. 242–244)

● LESSON: Why are living things needed in the soil?

Learnings to Be Developed:
Plants help to make soil by breaking up rocks.

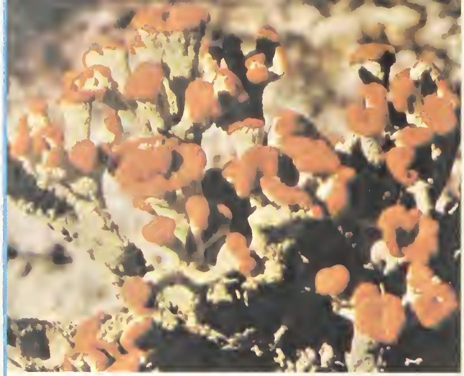
Lower plants do this by the chemical action of their by-products.

Higher plants break up rocks by the mechanical action of their root systems.

Soil is kept fertile by the action of microorganisms, worms, and insects and the decay of higher plants.

Developing the Lesson: Bring some moss on a rock to class. Study it under a hand lens. Discuss the pictures on page 242. Ask:

- *What color predominates in the moss and lichen plants?*
- *Do they perform photosynthesis?*
- *Do you think they require light?*
- *Where do you usually find plants such as mosses and lichens?*
- *Do you see any structures with the hand lens that you cannot see with the naked eye?*
- *If all the land was once solid rock, which plant type, lichen or moss, was probably the first to develop?* (Lichen.)



Lichens

Moss

Plants as Soil Makers

Plants also change rocks into soil. The picture at the top of the page shows a rock covered with a crusty plant called **lichens** (LY-kunz). Like other living things, lichens use oxygen and give off carbon dioxide. Some of the carbon dioxide dissolves in water. When this happens, a weak acid called **carbonic acid** (kahr-BON-ik) is produced. Carbonic acid slowly dissolves some of the minerals in the rock. This produces small cracks in the rock. Bits of the rock break off and become mixed with dead pieces of the lichens. Slowly this mixture of rock and plant material increases. After some time, enough of the mixture is produced so that other plants can live on the rock. The mixture is becoming soil.

Moss is one of the plants most capable of living in this newly formed soil. As the moss grows, it produces carbonic acid also. Slowly more and more of the rock is broken up. More dead plant material is mixed with the rock particles. Other plants, such as ferns and grasses, now find the soil a suitable place to live. The rock continues to be broken up as each new kind of plant becomes established in the soil.

After hundreds of years the rock is covered with a thin layer of soil. Very slowly, the soil layer becomes deeper and deeper. After thousands of years, plants such as shrubs and trees can grow in the soil. Their roots grow through the soil to the rock beneath it. Some of the roots enter cracks in the rock. As the roots in cracks grow thicker, the rocks are broken up even more.

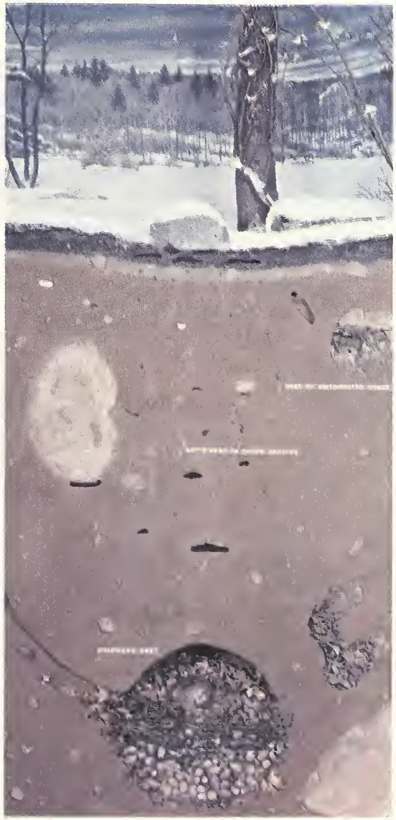
You might want to try to make a lichen garden. Collect rocks with lichens growing on them. Arrange the rocks in a glass jar containing a small amount of water. Cover the top of the jar with a piece of glass or cellophane. If you have a microscope, examine a sample of the lichens torn from the rock. Examine this sample near the torn edge. What does it show you about lichens as soil makers?

Living Things in the Soil

Most soils on the earth have been produced from rock that has been broken up. Soil scientists believe that it takes about a thousand years for one inch of soil to be made.

As you can see in the picture at the right, many different kinds of living things find the soil a suitable place in which to live. Each one adds something to the soil. For example, earthworms and insects that dig into the soil make tunnels through which air and water can enter the soil easily.

To find out what soil contains, spread about a cup of soil over a sheet of paper. Pick out objects that you can identify. Put them in separate piles. Examine some of the soil with a magnifying glass or a microscope. What kinds of materials did you find in the soil? From where did these materials come?



This is a cross section showing life in the soil. What forms of life do you see? How do they survive beneath the soil? How do they get air and food? Notice that this picture shows what the soil looks like in winter. Would life in the soil be different during the summer months? Explain your answer.

Have a pupil check with the county agricultural agent or agency and have him make a report on the predominant soil type of the county. Perhaps, if the agency is near, a field trip would be possible.

Background: Lichens are found under Arctic snow, in tropical rain forests, on barks of trees and rocks. Unlike mosses, which are usually found in the same places, they are not a bright green. The reason is that lichens are an example of *mutualism*. Two organisms, an alga and a fungus, live in close association for mutual benefit. The alga is a producer; the fungus is a consumer. The fungus protects the alga from the adverse conditions in the environment. The almost inseparable combination of the two led early biologists to classify them as a single type of plant.

○ **ADDITIONAL ACTIVITIES:**

Grow some lichens or mosses under the conditions listed on page 243. Attempt to grow another batch in a dry environment. Attempt to grow still a third batch in the absence of light.

Provide pans or small aluminum cups of soil to teams of pupils and invite them to classify all the substances in them. Vary the soils. Suggest the following possible approaches: separate by screening; wash out substances with water; filter; grow bacterial and/or fungus cultures in petri dishes; examine by microscope.

TEACHING SUGGESTIONS
(p. 244)

Background: The answers to *Using What You Have Learned* are:

1. Matter is in a state of dynamic equilibrium in a "balanced" aquarium. Oxygen, for example, is released by the plants, dissolved in the water, taken in by the fish's gills, combined in the fish's cells with glucose to provide energy, released to the fish's blood in combination with carbon (carbon dioxide) and finally discharged to the water through the gills. The carbon dioxide is taken up by the plant and is involved in photosynthesis to make a carbohydrate.

2. You will find that the rates vary with each species of plant. Nongreen areas will produce few or no bubbles of oxygen. The test for oxygen is to insert a glowing splint into a test tube in which the gas has collected. If the splint bursts into flame, the gas is oxygen.

3. Over 75 per cent of the earth's surface is covered by oceans. Of the remaining quarter, much is not plant bearing.

4. The root hair has most of its surface exposed to the environment. Its ability to absorb water is similar to that of a one-celled alga.

5. The epidermis protects against the invasion of foreign substances.

The Use and Reuse of Materials

When plants and animals in the soil die, bacteria and molds use them for food. Bacteria and molds obtain energy and materials from dead plants and animals. When dead things decay or decompose, the mineral elements in their bodies return to the soil. They return in a form that plants can use again. Then they can be used again by animals.

Whether living things are in the soil, on the land, or in the ocean, when they die their bodies decompose. The elements in their bodies return to the soil or water and are used again. Living things do not destroy materials. They only use them for a while and then return them to the earth. This is one of the major ideas of science—under ordinary conditions, matter can be changed, but it cannot be destroyed.

Using What You Have Learned

1. How can an aquarium show one of the major ideas of science—that under ordinary conditions matter may be changed but not destroyed? Make an aquarium to find out. What is meant by a balanced aquarium? How does a balanced aquarium show that plants and animals need each other?

2. Obtain some water plants from a pet store or pond. Set each plant in a small jar of water in a sunny place. Watch for bubbles to appear. What are the bubbles? Do they occur at the same rate for each kind of plant? Do they occur in the same parts of the plants? How can you make certain what the bubbles are?

3. Can you explain why you would expect 90 per cent of the green plants on the earth to be found in the oceans?

4. How is a root hair somewhat like a one-celled green plant in the ocean?

5. In what way does the epidermis of a leaf resemble your skin?

How Plants and Animals Survive

Look at the three pictures on page 246. One is a forest, and another is a meadow next to the forest. There are different kinds of grasses growing in the meadow.

There is very little grass growing in the forest. Grass is one kind of plant that needs a large amount of light. Can you tell why there is very little grass growing in the forest?

Look at the other picture on page 246. This is a picture of a meadow high in the Rocky Mountains. Its elevation is about 12,000 feet above sea level. Trees cannot grow at this altitude, because the soil is frozen at depths where the roots of trees would grow. The soil loses heat very rapidly, because the air is thin at this altitude.

Look at the picture on page 247. It shows a grassland prairie. The land is covered with grass, but no trees grow there. The soil is deep and fertile. It is not frozen in the summertime. Trees do not grow there because there is not much water. Trees do not generally grow well in places that have an annual rainfall of less than twenty-five inches. This grassland prairie has only twenty inches of rain each year.

The other picture on page 247 shows a desert. There is very little grass. The soil is good, but there is little water. Generally, there is less than ten inches of rainfall a year in the desert.

As an activity, one student might bring in a rainfall map. Try to pick out parts of the country where you would be most likely to find trees, grasslands, and deserts.

When the early settlers first came to the eastern part of the United States, they found most of the land covered with forests. Trees grew well in that part of the country because the rainfall was more than twenty-five inches a year. Since that time, trees have been removed from much of the land. The land was used for farming. Some of the farms produced good crops, but others did not. Some of the farms that failed to produce good crops did not have the proper kind of soil for crop plants. In other words, the soil was suitable for trees but not for crop plants.

Light, temperature, water, and soil largely determine what kinds of plants will grow in a place. Which condition determines why grass will not grow in a forest? Which one determines why trees will not grow in high mountain places? Which one determines why trees will not grow well on the prairies? Which one determines why crop plants will not grow well in some places where forests have been removed?

TEACHING SUGGESTIONS
(pp. 245–249)

LESSON: What are the climatic conditions necessary for growth of various plant types?

Learnings to Be Developed:

The climate of an area to a large degree determines the types of plants that predominate.

A combination of temperature, solar radiation, and rainfall determines the amount of photosynthesis taking place.

Scientists classify areas of the world according to the types of life that are predominant in them.

Developing the Lesson: Since climate plays a most significant role in the growth and survival of the organisms in any community, a study of the relation between climate and living things is a necessity for a background in science.

After reading this page ask:

- *How is solar energy distributed over the earth?* (Different places receive different amounts of solar radiation. Through the year, regions near the equator receive the most and the polar regions receive the least. Two of the contributing factors should be pointed out. First, the atmosphere absorbs some of this energy; the denser it is, the more it absorbs. Near the poles the

radiation must penetrate more atmosphere, because it enters at a flat, or very oblique, angle. At the equator it is quite direct and has less distance to penetrate. Secondly, the earth's surface near the equator receives a concentration of direct radiation. At the poles, due to the curvature of the earth, this same amount of radiation would be spread over a greater surface area.)

How is solar energy distributed at a given place over a year?

Here review the changes in axis tilt which account for the seasons.

How is the atmosphere heated?

Solar radiation has small direct effect on atmospheric heating. Most of the heat in the air is derived from the heated surface of the earth. This accounts for the basic atmospheric circulation. Major vertical air currents are found at:

the equator: heated, rising air
about 30° N. and S.: cooler, descending air
about 60° N. and S.: warmer, rising air
the poles: cold, descending air

As the earth rotates on its axis, these rising and descending air currents flow in a pattern on the earth's surface. This pattern sets up the prevailing westerlies, trade

Here you see a picture of a meadow high in the mountains. Why is it trees do not grow well in this environment?

Have you ever walked through a forest? Was there much grass on the ground? Where would you find more grass—in a meadow or a forest? Explain your answer.

COMPARING ENVIRONMENTS

On the right is a grassland prairie. This grassland prairie gets very little rain. Why is it trees do not grow well in this environment?

Below is a picture of a desert. Why are very few plants found in this environment? What plants grow well in the desert?

winds, easterlies, and calm horse latitudes.

- *How is moisture brought to land areas?* (Circulating air currents, winds, and breezes carry moisture from ocean areas.)

Warm air can hold more water vapor than cold air can. Warm air passing over warm oceans picks up moisture. If this air later becomes cooled, it will release its moisture as rain or snow. This cooling could occur in a variety of ways. Cooler land masses could cool the air. A cooler air mass could meet a warm one and reduce its ability to hold moisture. Air passing over a high mountain cools as it rises and drops moisture on the windward side of the mountain.

ADDITIONAL ACTIVITIES:

Have pupils, individually or as teams, design land-use maps. Consult atlases and other sources.

Assign teams of pupils to collect pictures, charts, and information regarding the earth's major natural regions of climate and vegetation. Suggest that they arrange their information as follows: Name, location, climate, vegetation.

Tundra: High latitudes and altitudes; polar climate below 50° in

summer; moss, lichens, low grass growth with occasional stunted trees, some areas bare, some flowering plants.

Evergreen forest (Taiga biome): West coasts N. of 60°, east coasts N. of 45°, across continental interiors; severe winter climate and deep frost, maximum summer rainfall and short growing season; forests chiefly of evergreen, needle-leafed trees such as spruce, fir, and hemlock and some deciduous trees such as larch and willow.

Mixed forest: Two locations: East sides of continents between 25° and 45°, west sides of continents between 40° and 60°; mild winter climate with rain in all months, winter snow of short duration, hot summers in East, cool summers in West; forests of broadleaf deciduous trees at times mixed with pine, some pure pine forests.

Mediterranean scrub woodland: West coasts of continents between 30° and 40° in both hemispheres; mild, wet winters and dry, hot summers; scattered evergreen, broadleaf trees, large areas covered with evergreen brush.

The Regrowth of a Forest

Fires may destroy all the plants that once grew in a pine forest such as that shown below. What would happen to the burned-over land if it were left alone? After a long time, it would again be covered with pine trees. But pine trees would not be the first plants to grow. The first would be plants such as those shown below on the right. The seeds would come from other places. By what methods would the seeds be carried?

For several years, these plants and others like them would grow very well on the burned-over land. Before long, small trees would begin to appear. These would be not pine trees, but

Each year, fires destroy millions of acres of our valuable forest lands.

aspen. Aspen are broadleaf trees and grow more rapidly than pines. The aspen would soon reduce the light so that many of the other plants would die out. After several more years young pine trees would begin to appear among the aspen. Young pine trees grow so well beneath aspen that after a number of years they would grow taller than the aspen. The aspen would not get enough light and would begin to die. After many, many more years the pine trees would take over. A new pine forest would replace the forest that had been destroyed by fire several hundred years earlier. The land would return to a pine forest because the growing conditions are best suited for pine trees.

Read the text and tell why a burned-out pine forest will again become a pine forest.

Prairie: On dry margins of midlatitude forests; midlatitude humid climate, hot summers with maximum rainfall; tall grass, with forests near stream valleys.

Steppes: Transition between humid forest land and dry lands; midlatitude semiarid climate with heavy summer rainfall; short grass, sparse forests.

Deserts: West coasts usually between 20° and 30° and continental interiors in middle latitudes; arid climate; scattered cactus and other drought-resistant plants, mostly bare ground.

Savanna or *Tropical Woodland:* Low latitudes; low-latitude climate, no month below 65° F., year with a rainy season and a long dry season; tall grasses and scrubby deciduous woodlands.

Tropical forests: East coasts of continents for about 25° either side of equator, west coasts about 10° either side of equator, and equatorial lowlands; rainy climate, no cool season, unusual rainfall in wet season, and less rainfall in "dry" season; forests of broadleaf trees, deciduous and evergreen.

TEACHING SUGGESTIONS
(pp. 250–252)

LESSON: How does plant succession show adaptations for survival?

Learnings to Be Developed:

Plant communities change with time.

As changes occur, organisms must adapt to the new surroundings or else die out.

Those plants and animals best adapted to the new conditions survive and replace the less fit.

Developing the Lesson: After the class has read pages 248–252 ask:

- *Why do plant communities change?* (Changes in soil composition, acidity of soil, and moisture all contribute to changing the environment. Newer plant life can cope with the new surroundings. Catastrophic events such as fire, flood, tornado, or volcanic eruptions may be responsible for change. Man exerts his influence over plant life in many ways that change the environment.
- *As a plant community changes, do you think that the animal community would change?* (As a plant community changes and becomes more dense, populations of animals that it can support will usually increase in both numbers and variety.)

On the left are sunflowers. On the right are tumbleweeds. Tell how land covered with sunflowers and tumbleweeds becomes a grassland.

The Regrowth of a Grassland

Suppose that a farmer plows up the grass on part of a prairie so that he can grow wheat on the land. After several years, he finds that the land will not grow enough wheat to support him and his family. He leaves his prairie farm. What will happen to the land?

Since growing conditions are best suited for grass, the land will someday become a part of the grassland prairie again. But grass is not the first kind of plant to grow. Tumbleweeds and sunflowers, like those shown in the pictures, grow first. After several years, small patches of grass begin to grow from seeds from surrounding grasslands. Each year, the grass covers more and more of the land. Less water is available for the tumbleweeds and sunflowers. What do you think will happen to them?

Adaptations of a Pine Tree

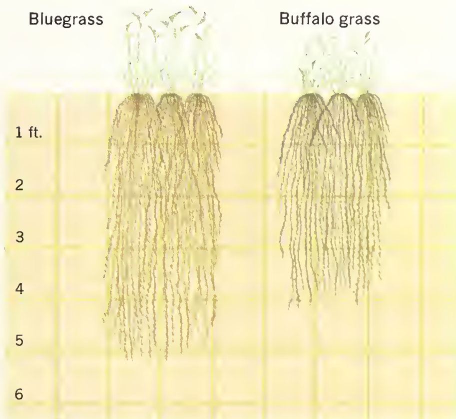
Why will pine trees eventually take over the land where a pine forest once stood? Why will grass eventually take over where there once was a grassland? The answer to both questions is that each is better suited than other plants to grow on that land. The pine trees and the grass are better *adapted* to the environment.

Let us take a look at the ways a pine tree is adapted to its environment. First, young pine trees grow well in reduced light. That is why they are able to grow among the aspen. Second, the pine trees' roots grow deep into the soil. They can get water from deeper in the soil than the aspen can. Third, they grow taller than the aspen. When this happens, light beneath them is reduced. The aspen are not adapted to reduced light. In these three ways, pine trees are better adapted than aspen to the place where a pine forest once stood.

Adaptations of Grasses

In what ways is grass better adapted than the tumbleweed and the sunflower to a prairie environment? Tumbleweeds and sunflowers are rapid-growing plants. Those shown in the picture on page 250 grew from seeds in about three months. Before the plants are killed by cold weather in the winter, they produce many seeds. The seeds can live in the frozen soil during the winter. In the spring, when the soil becomes warm, seeds germinate and another crop of tumbleweeds and sunflowers grows.

How does grass compete with tumbleweeds and sunflowers? Grass seeds are carried in from surrounding grasslands. Like the tumbleweeds and sunflowers, grass produces seeds each year. But the old grass plant is not killed by cold weather. Since the grass does not die each winter, its roots spread through more of the soil



These two kinds of grasses grow on the prairie. How do their root systems enable them to live in very dry regions?

How do new plants get to a community where they did not previously exist? (Seeds may be introduced into an area by wind—dandelion, orchid, tumbleweed, thistle, maple; by clinging to animal fur—cocklebur; by being eaten and then deposited in animal droppings—berries; by animals that carry and secret a cache—nuts and acorns; by water—the coconut.)

ADDITIONAL ACTIVITIES:

Show a succession of types in protozoa. Make a hay infusion. If hay is not available, take some dried leaves and grass from the base of school plants. Place this in a gallon jar with warm water and put the jar aside for a few days. Examine a small sample of water under the microscope or microprojector every few days over a few weeks' time. A succession of microscopic organisms should be noticeable—much the same as a plant succession.

Secure a square foot of sod. Study its subsoil structures; root systems and runners. After washing out all soil, compare the length of the root systems with the Bluegrass and Buffalo grass.

If the school has a gr wing garden under student care, allow one small section to go wi hout w eding for a protracted period

TEAC HING SUGGESTI NS
(pp. 252–253)

LESSON: What is an adaptation?

Background: In any discussion of adaptations, keep in mind the definition in terms of modern biology. An adaptation is a characteristic that enables an organism to meet the needs of its environment. This characteristic is usually determined by hereditary factors. A plant that has a short root system does not develop extraordinarily long roots because surface water is sparse. The pine tree does not outgrow the aspen for sunlight. The large water-bearing cells of the cactus do not develop because it is a long time between drinks. The water lilies do not develop air tubes because air is scarce in the water. All these characteristics are inherited. The mechanism of their original development we can only surmise.

Learnings to Be Developed:

An adaptation is a quality or set of qualities possessed by an organism that help it survive in its surroundings.

These traits, or qualities, are inherited.

Under changing surroundings some traits prove advantageous; others do not.

than can the roots of the tumbleweeds and sunflowers. The picture on page 251 shows the root systems of two kinds of grasses that grow on the prairie. Note how dense these root systems are. How would these root systems adapt the grasses to living on the prairies?

Dig up a clump of grass from a vacant lot or field. Wash the soil from the roots by moving the clump up and down in a bucket of water. Is it possible for you to count the number of roots on one clump of grass?

Carefully dig up a dandelion plant that has been growing in a lawn. Can you tell why grass does not grow near the dandelion?

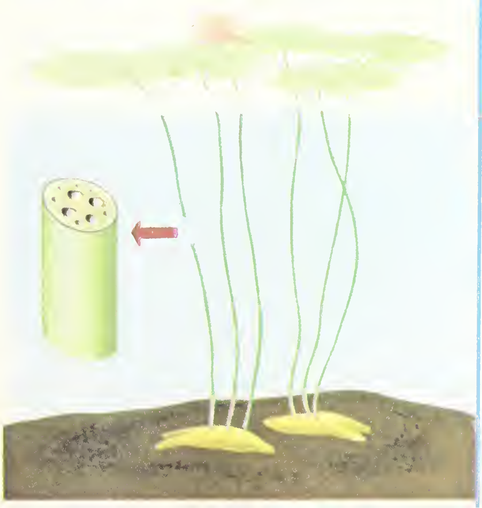
Adaptations of Cactus

A cactus plant is adapted in three ways to living where there is very little rainfall. First, the roots of a cactus plant spread over a wide area and do not grow deep into the soil. This makes it possible for the plant to absorb more water near the surface of the earth. How would this help the plant? Second, the stem of the cactus plant is very thick. It has many large cells in it. These cells can hold much more water than ordinary stem cells. How does this help the plant? Third, the leaves of a cactus plant are extremely small. In fact, they are the thorny spines on the stem. How does this help the plant?

Name three ways a cactus plant's structure enables it to survive in dry regions.

Adaptations of Water Lilies

The picture above shows plants growing in water. They are called water lilies. Some plants, such as bean plants, do not grow well in water. They die because their roots cannot get air from the water. How do the roots of water lilies get air? Air passes down from the leaves through the stem. The picture at the right shows the hollow tubes in the stem through which air passes. How does air get into the lily leaf?



Developing the Lesson: Start by asking such questions as:

- *What traits possessed by man allow him to play ball, typewrite, do arithmetic, and live on earth?* (Answers will vary, but such things as general lithesomeness, manual dexterity, developed brain, air-breathing mechanism, etc., should be among the responses.)
- *What traits would man need to survive on a planet twice as far away from the sun and twice as large as the earth?* (Stronger bone structure to support body weight under greater gravity; lung or oxygen-getting organ for new atmosphere, if one exists; stronger or larger heart to pump more blood and keep a higher pressure; additional or more effective temperature-control organs to compensate for loss of solar heat; etc.)
- *Why are "weeds" removed from a garden?* (Usually for aesthetic reasons; however, many weed varieties would overcome the plants wanted in the garden.)
- *Why is crab grass not wanted in a garden?* (It is unsightly and its system of runners allows it to spread rapidly. It crowds out most of the finer grasses.)

Discuss the idea of adaptations and how some adaptations are

beneficial and others harmful or useless. The example of the use of lungs on land versus the use of lungs in water, or the use of lungs on earth versus their use on the moon would be a good one. Ask for others from both plant and animal kingdoms.

Observe the pictures on pages 251, 252, and 253, and discuss the content of the reading. Try not to leave the impression that the adaptations occur because of the conditions met.

ADDITIONAL ACTIVITIES:

Visit a field that is not now under cultivation. Observe plant types and attempt to find some hints of succession. Does the field have a dominant type of plant? How long has it been left undisturbed?

Make a planting box containing good soil. Mix up a variety of seeds, an equal number of each plant (flowers, dandelion, lima beans, tomato, grass, etc.). Allow these seeds to grow under the best of care. Supply adequate water and sunlight. Observe for succession and final emergence of a climax plant. This will take some weeks, so daily observations should be made and recorded. The value of numbers in science could be stressed here in the observations.

Adaptations of Animals

You know that there are many different kinds of animals in different parts of the earth. Large herds of buffaloes once lived on the prairies in the United States. Here they found the grass they needed for food. Buffaloes could not have survived in a forest.

Deer are found in and near forests. Deer live on the tender shoots and leaves of trees and shrubs. Could deer survive on a prairie?

Camels, which are used for doing work in the Middle East and North Africa, can go many days without water. They can also run easily over both sand and hard rock on their flat, padded feet.

Reindeer, which live in the arctic regions, dig through ice and snow with their sharp-edged hoofs to find lichens. Like camels, they are strong runners—but could they survive in the desert?

Tree squirrels live where there are trees. They eat the seeds from trees and use trees as nesting and hiding places. The ground squirrel lives on the prairies. It lives in burrows and eats the plants that grow on the prairies. Could a tree squirrel live on the prairie? Could a ground squirrel live in a forest? Explain your answers.

Tree squirrel

Ground squirrel

Animal Protection from Predators

One of the most important problems animals have is that of protecting themselves from other animals. Animals that attack other animals for food are called **predators** (PRED-uh-terz). The mountain lion is a predator of deer. The coyote is a predator of rabbits. Some hawks are predators of smaller birds. In lakes and oceans, large fish are usually predators of small fish and fish eggs. In arctic waters, polar bears hunt and eat seals, which in turn live on the fish that they can catch through the ice.

Some animals have adaptations that help to protect them from other animals. For example, the porcupine's body and tail are covered with sharp, pointed quills. These quills usually lie flat on its body, but when the porcupine is disturbed, the quills stick out, as in the picture above at the right. When the porcupine is attacked by another animal, its quills stick into the animal. When the animal moves away, the quills go with it! Each quill has sharp barbs, like a fish hook, and it is very difficult to remove.

Male deer have antlers, which they use to protect themselves from coyotes and mountain lions. They may also use their hoofs. However, the best protection that the deer have is their ability to run very fast.

You have learned about two ways animals protect themselves. Can you name other ways? How do dogs and cats protect themselves? How do birds and caterpillars protect themselves?

TEACHING SUGGESTIONS
(pp. 254–257)

LESSON: What are some animal adaptations?

Learnings to Be Developed:
All animals have traits that enable them to exist in their natural surroundings.

Removal from the natural living conditions frequently causes extinction.

Since many animals prey on others, some adaptations are defensive.

Developing the Lesson: Depending on the locale of the school, begin discussion by appropriate questions.

- *How is a cat adapted to catch mice?* (Its silent tread; its ability to remain quiet during long periods of waiting; its ability to pounce; eyes that can perceive in dim light.)
- *What are the traits that protect chickens from birds of prey?* (Very little other than the general panic and noise.)
- *Did the American buffalo, or bison, have sufficient adaptations for survival?* (Probably he did for prairie life. Man's unintelligent slaughtering of herds is responsible for their present state of near extinction.)

Continue discussion covering the examples of predators on page 255.

Background: The small Key deer of Florida lives in marshes. Its adaptations are such that it thrives in this area but would face extinction in northern forests. It is small and can hide in clumps of marsh grass.

Developing the Lesson:

- *Do you know of other animals that are protected by coloration?*

Salamanders take on the coloration of their background. Brush birds, such as pheasant and quail, have a coloration that blends with their background. Desert animals such as lizards, grasshoppers, beetles, and mice living at White Sands National Monument, New Mexico, are white; nearby, where the sands are darker, the same species have darker coloration. Some birds have a summer plumage and a lighter winter plumage. The green backs of frogs blend with the water or plants on which they rest. Investigate other animals for furthur coloration protection, e.g., polar bear, caterpillar.

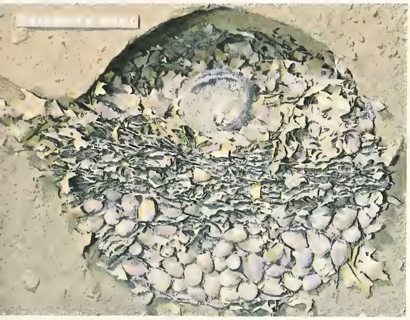
A young deer, or fawn, is protected in another way. As you can see in the picture above, the coloring of the fawn's coat makes it difficult to see. This is called **protective coloration.** Do you know of other animals that are protected by coloration?

Hibernation and Migration

Animals are adapted to seasonal changes in temperature. Some animals, such as woodchucks and ground squirrels, sleep during the winter. This is called **hibernation** (hy-ber-NAY-shun). Animals that hibernate eat a great deal of food during the summer, and they are quite fat by the time winter comes. During their long winter slumber, they do not eat. The fat in their bodies keeps them alive. Do you know of some other animals that hibernate?

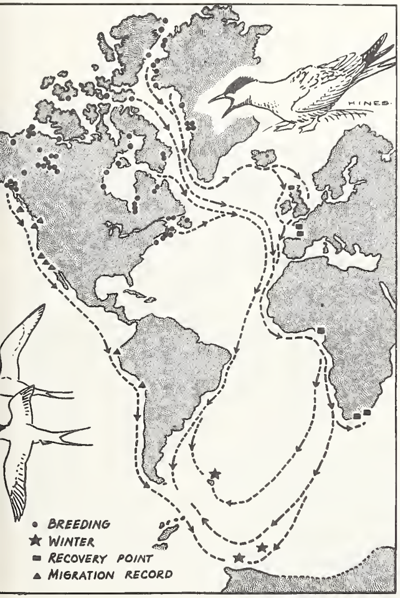
Some animals move from places where it is cold in the winter to places where it is warmer. This is called **migration** (my-GRAY-shun). Many different birds migrate from the north to the south during the Northern Hemisphere's winter. Some birds migrate great distances. For example, the arctic tern travels 10,000 miles from its summer home in the northern part of North America to its winter home near the southern tip of South America. The bobolink is another great traveler. It spends the summer as far north as the Hudson Bay in Canada. It spends the winter in Argentina, South America. Name some birds that spend only a part of the year where you live. Where do they go for the rest of the year?

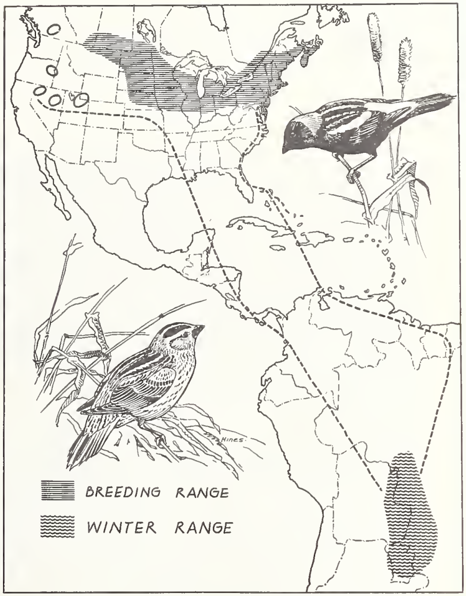
Why do only some kinds of birds migrate? How do they know when to begin their migration? How do they find their way? Scientists are still trying to find the answers to these questions.



The Chipmunk spends much time under ground in a nest during the cold days of the winter.

The ground squirrel spends the winter hibernating underground. Look at the two maps below and tell how the arctic tern on the left and the bobolink on the right spend their summers and winters.





• *Name some other natural protective devices of animals.* (Armor plates: turtles, armadillos, clams. Repugnant glands: skunk, stink-bug, octopus. Claws and tearing teeth: wolves, dogs, tigers. Poison glands and fangs: snakes, insects, spiders.)

Background: An animal in true hibernation cannot resume its activity until the temperature of the environment increases. Examples include ground squirrels, chipmunks, woodchucks, and frogs. Bears, skunks, raccoons, and opossums have a winter sleep in a protected place, but their body temperatures remain the same.

While we usually associate migration with birds, some mammals also migrate. The bighorn sheep lives in high Rocky Mountain meadows in summer and comes down in winter. Olympic elk follow the same routine. Other migratory animals include the fur seal, the monarch butterfly, some ocean turtles, and salmon.

TEACHING SUGGESTIONS
(p. 258)

● **LESSON:** Living and nonliving things contribute to changes in the environment.

Learnings to Be Developed:

Animals use the materials of their surroundings and leave traces of their usage behind.

Physical and chemical changes occur that keep the environment in a state of change.

Developing the Lesson: Discuss the picture of the pond with reference to what is apparent as well as to what may be inferred.

- *What is the present state of the pond?*
- *What is the value of the duck life on the pond?*
- *What do the ducks need to keep their environment ideal?*
- *Does the vegetation depend on the pond and its contents?*
- *What organisms probably live in the area shown by the picture?*
- *Other than the physical changes mentioned in the book, what happenings could change the pond?* (Many answers. Suggestions: Beaver dams might increase the pond depth or might lessen the water flow; a series of events would follow either.)

How Environment May Change

Different kinds of living things are found in and around a pond. Several kinds of fish and water insects can be found in the pond. Ducks and other water birds can be seen on the water. Water lilies grow in the water near the edge of the pond. Cattails and other kinds of high grasses that are adapted to wet soil surround the pond. Here and there are some birch trees and shrubs that can live in moist soil. The surrounding hills are covered with trees.

Each kind of plant and animal is adapted to the special conditions under which it is living. But the environment is constantly being changed by the plants and animals living in and near it. As the water plants and animals die, their bodies slowly fill the pond. As rain water runs from the surrounding land into the pond, it carries dead leaves and other material. Slowly the pond becomes smaller and smaller. After many years, there will no longer be a pond. What plants and animals will no longer be living there? What new ones will move in?

How many years back can you remember? Has the place where you live changed much in that time? Are the summers warmer? Are the winters colder?

How may this environment change in time?

The United States—20,000 Years Ago

If you had been living in the United States 20,000 years ago, you would have found it very different. At that time a sheet of ice extended from the North Pole over most of the northern part of North America, which was colder than it is now. The time was known as an "ice age." During the past million years there have been four ice ages. Ice sheets reached as far as the places now occupied by St. Louis, Missouri, in the Midwest, and New York City, in the East. The sheets of ice were as much as a mile thick. As they slowly moved southward, they pushed soil and rocks ahead of them. Most of New England's good soil was scraped away by advancing mountains of ice. The soil and rocks were pushed into the ocean off the coast of Connecticut. The strip of land known as Long Island was formed from New England's soil and rocks.

You can see that the environment changed greatly during the ice ages. Animals that lived in the northern parts of the country moved south ahead of the cold ice. Plants were destroyed. As it became warmer, the ice slowly melted. Animals moved northward again. Plants began to grow again on land that had once been covered with ice.

These changes took place gradually. It has taken about 20,000 years for the ice to melt back as far as the ice cap that now surrounds the North Pole. In the years since Columbus discovered America, for example, it has not been possible to observe any great change in temperature. Recently scientists have been trying to find out whether the ice cap around the North Pole is getting larger or smaller. If it is getting smaller, the ice is still melting. Some day the Arctic Ocean around the North Pole may have much less ice in it. If the ice cap is getting larger, another ice age may have begun. If this is true, then 20,000 or more years from now the land may again be covered with ice.

A Rapidly Changing Environment

Of course, there are ways in which the environment can change very rapidly. For example, in 1883 a volcano erupted on the small island of Krakatoa, near Java, in the East Indies. The eruption was so violent that every living thing on the island was destroyed. Since then scientists have carefully studied Krakatoa to learn more about how living things become established again.

Three years after the eruption, there were 26 different kinds of plants growing on Krakatoa. Ten years later, the

TEACHING SUGGESTIONS
(p. 259)

● **LESSON:** Do all changes take place within a man's lifetime?

Learnings to Be Developed:
Most great changes in the environment take thousands of years.

We have indications that great changes are taking place even today.

Developing the Lesson: Refer to a map of the eastern seaboard of the United States. Point out Long Island as the scraped-off surface of New England, deposited at the front of a glacier that melted. Show that the continental shelf extends miles out into the Atlantic. This was a build-up that took millions of years. New York harbor is really a drowned valley. The true mouth of the Hudson River is many miles out in the ocean.

Refer to maps of other sections of the country. The oil lands of the Southwest were once under water, and the strata reached by the deep mines of coal regions were forests and marshlands.

It is probable that Australia was once part of the mainland of Asia.

An excellent reference to use here is *Things Maps Don't Tell Us,* by Armin K. Lobeck (Macmillan, 1956).

TEACHING SUGGESTIONS
(pp. 259–260)

● **LESSON:** Are some changes on the surface of the earth more rapid?

Learnings to Be Developed: From time to time rapid changes take place that are due to volcanic action, winds, and earthquakes.

Developing the Lesson: Since windstorms are frequent throughout the United States, call upon the children to cite examples of landscape changes that have been made rapidly by the action of wind. Tornados in the Midwest and hurricanes in the East and South should evoke answers that are within the experience of a normal class. Some coastal islands have been eliminated while some were newly formed, by the action of a single storm.

Volcanic action in the U.S. has been slight in recent history, but the marks of past volcanism are still with us. The Hawaiian Islands, dozens of mountain peaks in Alaska and the Aleutians, and the Palisades of New Jersey are all examples of volcanic action.

The only volcano in the coterminous U.S. that has erupted in recent times is Lassen Peak, in northern California. It erupted in 1914 and again in 1915.

A volcano burns near Krakatoa. Steam and gases rise high as hot lava pours forth.

island was plentifully covered with green plants. Twenty-five years after the eruption, 263 different kinds of animals were living there. Less than fifty years after all life had been destroyed on Krakatoa, the island was again covered by a young forest. Many more kinds of animals had also become established since the eruption. How did all this happen? From where did the plants come? How did they get to Krakatoa? From where did the insects and birds come? How did they get to Krakatoa?

Have you ever seen land from which all plants were removed? This often happens when houses or highways are being built. How long did it take before plants were growing again on the land? As you can see, it would be extremely difficult to destroy all living things on the earth.

The stories of the following volcanos are worth checking in the library: Paricutin, Mexico; Mauna Loa, Hawaii; Vesuvius, Italy; Etna, Sicily; Krakatoa, Indonesia.

Dandelions and Codfish

If you help to take care of a lawn, you know how difficult it is to keep the weeds out of it. The dandelion is one kind of weed that seems to grow well in lawns. You can dig dandelions out of your lawn, but soon new ones take their place.

Why are dandelions so difficult to control? One dandelion plant produces a number of flowers. Each flower produces many seeds. Each seed is attached to a small "parachute" that is easily carried by the wind. Dandelions begin producing seeds early in the summer. During the rest of the summer, dandelion seeds are being distributed. Because of the large number produced, it is likely that some of them will be carried to your lawn. Many of them will lie on top of the

grass and never germinate. However, some will be washed into the soil by rain. Some of these will germinate. Not all the seeds that germinate will develop into fully grown dandelion plants, but the ones that do will cause you trouble.

What would happen if all the seeds developed into dandelion plants? In a few years, your yard would be covered with dandelions. In fact, it would not be long before acres of land would be covered with dandelions. Can you tell why this does not happen?

Suppose each dandelion produced only one seed. What would happen to dandelions? One reason that dandelions are able to survive is that they produce a large number of seeds. How many seeds does a dandelion plant produce? You and your classmates can answer this question if each of you can find some dandelion plants. Carefully collect all seed heads from a dandelion plant. Count the number of seeds on each head. Find the average number of seeds per head. Estimate the number of seed heads produced by one plant during a growing season. Multiply your estimate by the average number of seeds. This will give you an approximate number of seeds per dandelion plant. It will be a large one. Compare your answer with those of your classmates.

Here is a chance to introduce some mathematics. Have the class determine the average number of seeds a plant bears.

TEACHING SUGGESTIONS
(p. 261)

LESSON: What adaptations of seeds make sure of plant survival?

Learnings to Be Developed:

Plant distribution is assured by the production of a lavish number of seeds in most varieties.

All the seeds do not germinate.

Enough do germinate to ensure survival of the species.

Developing the Lesson: Bring a few dandelion seed heads into class and blow them over the room as an introduction to seed dispersal.

Start discussion with:

- *How many children hear their parents complain about dandelions on the lawn?*
- *Does digging them out eliminate the problem?*
- *What control is used most effectively against their return?* (A chemical treatment that attacks broad-leafed plants but does no harm to blade plants such as lawn grasses. Some strains of lawn grass are so dense that dandelions cannot grow.)

Proceed with the questions asked on page 261. If the time of year permits, have the children count the number of seeds from one plant. They could do this as a field trip or else as a home assignment.

TEACHING SUGGESTIONS
(pp. 262–263)

LESSON: How does the interdependence of living things produce a balance among them?

Learnings to Be Developed:

When one organism feeds on a second organism, an overabundance of the first is prevented by the scarcity of the second.

When one organism in a community is affected by a change in its environment, it directly or indirectly affects all other organisms in the same community.

Developing the Lesson: Initiate discussion by studying the classroom aquarium or the one pictured here.

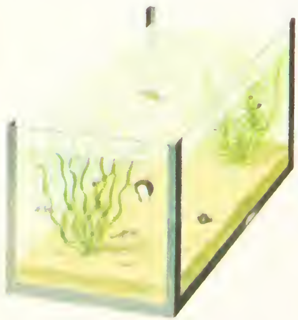
- *What living things are the main producers of food?* (The algae and aquarium plants.)
- *What living things are the consumers of food?* (The fish, the scavengers, bacteria.)
- *What would happen if the plant life grew so that it tripled in number?* (More food would be available for a while. More oxygen would be available for the animals. However, the crowded conditions would lead to crowding out of the fish. If the conditions were allowed to continue, even the plants would soon find less of the needed supplies for life.)

You know that large fish eat smaller fish and fish eggs. How, then, is it possible for some small fish, such as codfish, to survive? A female codfish lays as many as six million eggs at one time. Many of the eggs never hatch, because they are eaten by other fish. After the remaining eggs have hatched, many of the small fish are eaten by larger ones. Even though only one grown codfish may survive from one million codfish eggs, codfish remain in the ocean.

Interdependence of Living Things

In this unit you have learned about the ways in which living things are dependent on materials from the earth and energy from the sun. You have learned that green plants make the materials and energy available to other living things. Finally, you have seen how living things compete with one another for food, light, and water.

During the millions of years that life has existed on earth many kinds of living things have developed. So far, scientists have discovered more than a million different kinds of plants and animals. Each kind is dependent on other kinds in some way. Even green plants are dependent on bacteria and molds to decompose dead plants and animals. All living things are interdependent. The pictures on this page show some ways in which living things are interdependent. Can you explain the pictures?



Balance in Nature

The mule deer is adapted to living in a mountain environment where shrubs and small trees grow. Much of its food comes from the buds and tender leaves of these plants. Mountain lions are adapted to the same environment. Their food comes from the deer they kill. Generally, the deer population does not increase for two reasons. First, the shrubs or trees produce only enough food to feed a certain population of deer. If the deer population increases, there will not be enough food. Some of the deer will die. Second, the mountain lion kills enough deer to keep the deer population about the same from year to year. The population of mountain lions remains about the same because the population of deer does not increase. There is a balance between the mountain lion population and the deer population.

There are many other examples of balances between and among living things. In what way is each of the following pairs of animals in balance?

1. Owls and mice
2. Rabbits and coyotes
3. Small birds and hawks
4. Mantises and grasshoppers *
5. Ladybird beetles and cottony-cushion scales

Changing the Balance

What would happen to the deer population if all the mountain lions were killed? Hunters actually have killed them all in some places, and the results are well known. The deer population increases rapidly until there are more deer than the food supply can support. Many of the deer die of starvation, reducing the size of the population until a new balance is reached between the deer population and its food supply.

At one time it was considered necessary to kill hawks to protect birds and chickens. However, when the hawks were killed, the unwelcome mice and gopher populations increased. A good rule to follow is to find out the effects of reducing or increasing the numbers of one kind of animal before attempting to do so.

The idea that as civilization spreads, all wildlife becomes scarcer is false. Many animals have been very successful in adapting to the changed conditions brought about by man. For example, the coyote, the Colorado potato beetle, and the opossum have increased in numbers and spread to new areas. House mice, houseflies, bedbugs, sparrows, and starlings seem to live and thrive better in man-made environments than they do in the wild. Can you think of other examples?

The U.S. Department of Agriculture has actually colonized the praying mantis and introduced it into areas where the grasshopper is a pest to man.

Discuss the pairs of animals listed in column one. Answers are:

1. Owls and mice. Mice reproduce very readily: Their litters are from 3 to 12, and the gestation period is no more than 21 days. At this rate the mouse population would soon overrun the countryside or starve themselves into extinction. The mouse population is kept within reasonable bounds by owls who feed on mice and other small rodents.

2. Rabbits and coyotes. Rabbits are destructive animals to farmland, as are mice. Their rate of reproduction is large. The rabbit's natural enemy is the coyote, whose foraging territory extends over 20 to 30 miles. It can well match the rabbit in speed, since it has been timed at speeds up to 45 miles per hour.

3. Small birds and hawks. The relationship of this pair is similar to that of the pair above.

4. Praying mantises and grasshoppers. Grasshoppers, when unchecked, can devour entire fields of grain. Praying mantises are beneficial to man because of their appetite for insects. Grasshoppers are a preferred diet.

5. The ladybird beetle (or ladybug) and cottony-cushion scale. The scale is an aphid that destroys fruit trees. The ladybird beetle devours the scales.

TEACHING SUGGESTIONS
(pp. 264–265)

Background: In addition to the indiscriminant use of pesticides described in the biography of Rachel Carson, man has also made his environment unhealthy and unsafe by polluting the air and water around him. As the population of the United States increases, the amount of pollutants also increases, and at a greater rate than that of the population.

Air pollution is the presence in air of foreign particles, gases, and vapors that cause a nuisance or even disease. While smoke and soot have always been a nuisance, and complained about, it has only been since World War I that large-scale pollution of the air has made life in cities potentially dangerous. The burning of hydrocarbon fuels in homes, factories, and automobile engines releases into the air harmful gases that can cause respiratory diseases and some types of lung cancer. Chemical plants also release harmful chemicals into the air as by-products of their normal operation.

Air pollution can be controlled by improved methods of dispersal (e.g., the building of taller chimneys), more efficient incineration of wastes to prevent the escape of waste products into the atmosphere, the use of substitute fuels

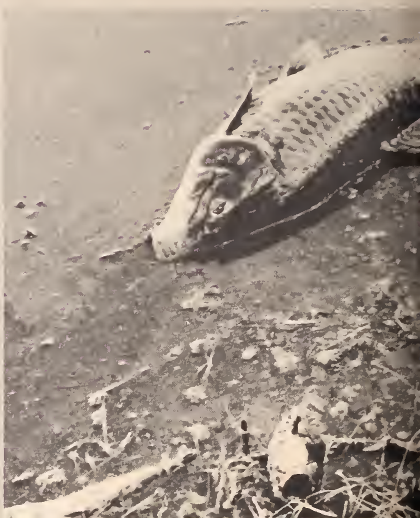
Rachel Carson

(1907–1964) United States

Rachel Carson was born and grew up in the small town of Springdale, Pennsylvania. There, and in the surrounding countryside, her mother taught her to love the world of living plants and animals. She learned from her mother that every living thing has its place in nature and performs some useful function. It is only mankind that thinks of some flowers as "weeds," or insects as "pests." In nature there are no "weeds," no insect "pests."

When Rachel Carson grew up she became a biologist. In her studies she learned that in all of nature there is a *balance* among all living things. This balance prevents plants and animals from doing harm to men, to the countryside, or to themselves. When the balance of nature has been upset for some reason, plagues and epidemics occur.

After college, Rachel Carson went to work in Washington, D.C., for the Fish and Wildlife Service. In her spare time she wrote books about the beauty and wonders of nature. These books—*Under the Sea Wind, The Sea Around Us,* and *The Edge of the Sea*—made her famous.



During World War II, many different insect poisons—pesticides—were invented to help protect our soldiers overseas against disease. DDT was the most famous. After the war, these pesticides were used by farmers to kill the insects that destroyed their crops. Many farmers used these pesticides without thinking of the upsetting effects that they might be expected to have on the balance of nature.

In the countryside, the chemicals soaked into the ground and were washed into streams by rain. The fish in the streams and rivers began to die. Birds who fed on poisoned insects also began to die. Meanwhile, an even more alarming process was beginning to take place. The insects themselves became immune to the pesticides and began to increase in numbers even as their natural predators were dying off. Slowly, silently, the balance of nature was being upset. Scientists began to worry about whether these poisons could upset the balance of nature permanently and harm mankind.

To warn the American people of what was happening to their country through the indiscriminate use of pesticides, Rachel Carson wrote her most famous book, *The Silent Spring.* The title refers to the silence that now greets the early riser in the springtime instead of the symphony of birdsongs he used to hear in the morning. Rachel Carson hoped her book would make Americans aware of the problems that arise from using pesticides. Whether it will or not remains to be seen.

that do not form harmful wastes (e.g., natural gas instead of coal or oil), and the control of automobile exhausts. California in particular has set up standards to prevent the pollution of clean air. In 1950, a law was passed to control the waste gases given off by automobile exhausts. In 1959, statewide standards for air control were adopted to which local communities must conform.

As the population continues to increase, *water pollution* has become an equally serious problem. The chief cause of water pollution is the dumping of wastes and garbage into streams without first treating the wastes to remove harmful substances. This makes the water unfit for drinking, recreation, irrigation, or industrial use.

The techniques by which water can be purified are simple enough. Suspended foreign matter can be removed by adding certain chemicals to water. These chemicals froth up when added to water and effectively trap the foreign particles. The froth then either rises to the surface or sinks to the bottom of the water. Water can also be purified and bacteria removed simply by passing the water slowly through a deep layer of sand. Bacteria can be removed by disinfecting the water with chlorine.

TEACHING SUGGESTIONS
(p. 266)

Background: The answers to *Using What You Have Learned* are:

1. A forest community is characterized by adequate rainfall and a uniform environment. Grasslands have moderate rainfall and are subject to drought.

2. Farmers did not realize that the environmental conditions necessary for forest growth were not favorable to crop growth. Drainage, fertilizers, and soil conditioners should have been used to control the environment.

3. The plant-succession cycle is a lengthy one. Immediate planting by man assures a rapid growth, as well as preventing erosion by wind and water.

4. A large number of seeds and adaptations of root systems make most weeds better suited to growth than the cultivated plant.

5. Refer to pages 254–256.

7. a. Many possibilities: changes in breeding habits of birds and small animals; effect on moisture evaporation and rainfall; changes in types of plant life; etc.

b. Complete or partial elimination of all life, depending on the amount of activity.

Using What You Have Learned

1. Why are there very few trees growing on the grassland prairies?

2. Why have farms been unsuccessful in some places where trees once grew?

3. Why are trees planted on burned-over lands even though trees would eventually grow there again if the land were left alone?

4. Why do weeds seem to grow better in your garden than the plants you want to grow there?

5. Give examples of some ways in which animals are protected from their natural enemies.

6. List ways in which the environment in your community has been changed by the activities of people. How have these changes affected living things?

7. How may each of the following change the environment?

a. Reduction of the average annual temperature for a long period of time
b. Increased volcanic activity
c. An upthrust of mountains
d. Much heavier than average rainfall over a period of several months

8. Tell how each of the following pairs of living things is interdependent.

a. Apple trees and bees
b. Forest trees and birds
c. Aquarium plants and fish
d. Green plants and bacteria
e. Aquarium snails and fish

Conserving Our Resources

We depend, as do other animals, on air, soil with its minerals, water, and all other living things. These are our *natural resources*. We have been using up these resources faster than they can be replaced. Chemical factories, paper mills, steel mills, food-processing plants, electric power plants, oil refineries, and hundreds of other kinds of industries use our natural resources to make medicines, newspapers, books, construction materials, foods, heating materials, and many other products and materials that are a part of our everyday lives. Industry has grown rapidly in this century. As new discoveries and inventions are made, industry advances to supply us with the products and materials of the scientific age. As industry tries to meet our needs, problems are created—minerals are used up, water and air become filled with the smoke and dirt of large factories, and animals and plants die as their environments are destroyed.

Whether we live on the farm or in the city, it is our responsibility to look toward the future and to plan so that tomorrow's world will have plentiful resources as we do today. Managing these resources is called **conservation.** *Conservation* means using our resources wisely.

Since conservation problems are mostly man-made problems, they can be solved by man.

Soil Conservation

Many forests have been cut down. As rain falls, it washes away the soil where there are no trees to hold back the water. The soil is washed away into gullies and rivers and finally into the sea.

Grasslands have been plowed up to plant wheat and other crops. They have been overused for the grazing of sheep and cattle. When land is misused in this way, rain and winds may carry much of the precious soil away.

Since the time when the early pioneers came to America, we have lost one third of our good soil. At the same time our population has greatly increased. We must raise crops and food animals to feed the population. We are faced with the problem of learning how to raise more and better crops and pasture animals without ruining what is left of our good soil. We must also learn how to build up more good soil.

On the next two pages you can see some of the ways man now manages the land to build up fertile soil and to prevent it from wearing away.

Have your school library order the Yearbooks of the Department of Agriculture and of the Department of the Interior. Your congressman or senator could help you get copies.

c. Changes in watershed by reason of stream diversion.

8. a. Pollination and nectar.

b. Insect elimination and nesting.

c. Carbon dioxide and oxygen.

d. Same as (c).

e. Snails are decomposers of fish droppings; decomposition releases carbon dioxide.

TEACHING SUGGESTIONS
(p. 267)

Background: What can be done by teachers to assist in overcoming the apathy of the general public concerning conservation?

The general education of every citizen demands that he understand the underlying reasons for water shortages, watershed protection, food surplus and shortages, air pollution, and changing patterns of employment. Principles of human and natural resources must receive greater emphasis than ever before. The teacher can begin this education.

A free subscription is available to teachers for the *Bulletin on Conservation Education*. Write to The Conservation Foundation, 30 East 40th Street, New York, N.Y., 10016.

TEACHING SUGGESTIONS
(pp. 268–269)

● **LESSON:** How can we use mathematics to study soil?

Learnings to Be Developed: Soil study uses mathematics as a tool for understanding.

Developing the Lesson: Pose some problems such as:

1. One rain storm washed 4 tons of soil per acre off a 20-acre cornfield planted in straight rows uphill and downhill. On a nearby 20-acre field where corn was planted in level rows around the hill, only 1/2 ton of soil per acre was lost. How much more soil was lost from the straight-row field?

2. Farmer Brown raised 82 bushels of corn per acre in a 30-acre field planted on the contour. His neighbor, Farmer Jones, who planted his corn the old way (uphill and downhill), had 35 acres of corn that produced only 70 bushels an acre. Which one had more corn?

3. Soil is being washed into a lake at an average rate of 40 acre-feet a year. The lake averages 20 feet deep over 50 acres. How soon will the lake be filled with soil?

4. An inch of topsoil weighs 140 tons per acre. How many tons are in a 40 acre field where the topsoil is 10 inches deep?

EROSION AND CONTROL

On the right you see a gulley formed by the forces of erosion. The pictures below show how the gulley was filled in and a ground cover grew over the land. How does the ground cover prevent erosion? Look at page 269. What methods are being used to prevent erosion?

5. When the Mississippi River is at flood stage, it carries enough soil past Vicksburg, Miss., every minute to cover 40 acres 7 inches deep. How many acres could it cover at the same depth with soil that flows by in 1 day?

Discuss the pictures and captions on pages 268–269 to bring out the methods man utilizes to conserve soil.

- *What does the word conservation mean?* (Have pupils look it up in more than one dictionary.)
- *Don't we have enough soil of the proper kinds for our present needs?* (Yes, in most places. In some areas we have surpluses. But conservation looks for the future and for a balance of use. In this country alone our population is expected to reach 210 million by 1975. This would require soil for 40 per cent more farm products than were produced in 1965. The demand for wood products by 1975 is expected to be 30 per cent more than in 1965.)
- *What conditions need checking in order to conserve soil and make it more productive?* (The U.S. Department of Agriculture indicates erosion, excess water [swamps], and unfavorable soil as main factors for unproductive land, in the order named.)

TEACHING SUGGESTIONS
(pp. 270–271)

LESSON: Is water a concern only to the farmer?

Learnings to Be Developed:
Crops, woodlands, and wildlife require water.

Industry requires water.

Every citizen needs water.

Developing the Lesson: Indicate that in the past man has first selected his living quarters and then attempted to change his surroundings accordingly. He has been partially successful. However, complete control of nature has so far eluded him. The result has been that one-fourth of the nation's population is troubled today by floods, water shortages, and water pollution. The metropolitan areas of the eastern seaboard have increasing problems.

Where does the water supply come from? (Rain, snow, hail, and sleet are the major sources of our water supply. Nationwide, about 80 per cent comes from surface sources and 20 per cent from groundwater.)

Why is the water not used up? (The water cycle — from clouds to land to ocean to atmosphere —constantly renews the supply.)

Water Conservation

Make a list of all the ways you use water in one day. A hundred years ago, people did not use much water for bathing and washing. There were no water fountains or water coolers. Industries used very little water compared to the amount used today. We use vast amounts of water in many, many ways. We are using it at such a rapid rate that it cannot always be resupplied by rain and snow fast enough to meet our needs. And so we have water shortages.

Rivers have always been a principal source of usable water. Today the waters of only a few rivers are usable. Most of our rivers have been ruined by sewage and industrial waste.

The Potomac River in Washington, D.C., was once a favorite swimming place for people who lived near it. Today, the river gives off foul odors on hot, humid days. Towns all along the Potomac have sewage-disposal plants, but none is large enough to handle the present volume of sewage. Therefore raw sewage enters the river. This condition is repeated across the land in many other rivers.

Towns, cities, and states are now passing laws to keep our waters clean. Industrial plants are finding other ways to get rid of their wastes. Better sewage-disposal plants are being developed. But there is still much to do to make our waters clean and safe.

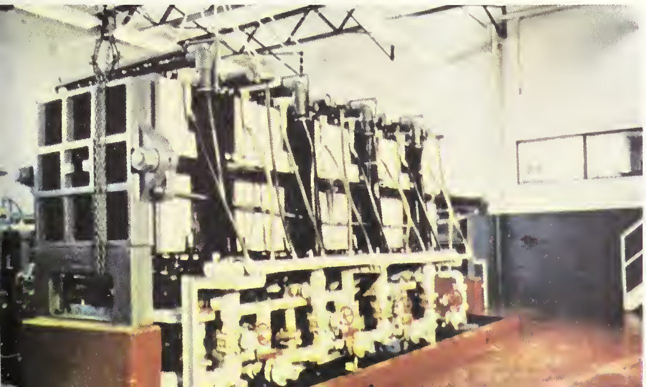
How may many floods be prevented?

Has there ever been a flood in your town? What caused the flood? Many floods occur after sudden and large rains or long-continued rains. The flood waters come from water that runs off the soil quickly. Water runs down bare hillsides or mountains at great speeds, swelling streams and rivers until they overflow and causing floods.

Flood water is water that did not have a chance to soak into the soil. The problem is how to give more rain water a chance to soak into the land. On the following page you will see some of the ways that have been developed to conserve water.

On January 1, 1965, The International Hydrological Decade began. For ten years, many scientists in many parts of the world will try to understand the water cycle better. This project is aimed at finding ways to prevent the loss of great amounts of water by evaporation and other natural and man-made means. Scientists also hope to encourage colleges and universities to train more scientists in hydrology—the study of water.

On the left, scientists test water samples for pollution. Above, you see a dam. How do dams conserve water? Below is a plant for changing sea water to safe drinking water.



- *If the cycle constantly renews the supply, why do we have problems?* (The amount of water needed is not necessarily delivered to all communities when it is needed. Precipitation ranges from 120 inches a year along the northwest coast to less than 5 inches in the arid southwest. Within a region, the water that falls is divided into separate portions by watersheds.)
- *What is a watershed?* (An area that collects and drains off water to a collection center, such as a stream, a lake, or an ocean.)
- *Does industry use much water?*

Children's answers should provide a stimulus to research in this area. Their estimates probably will be quite low. In the early 1960's industry used in excess of 150 billion tons of water annually — almost 50 times as much as *all other* industrial materials. Some specific examples of the water needed to produce 1 ton of manufactured material:

rayon: 300,000 gallons
rolled steel: up to 110,000 gallons
paperboard: up to 80,000 gallons
cane sugar: up to 100,000 gallons

To produce 1,000 kilowatt hours of electricity requires on an average 100,000 gallons of water in the form of steam or falling water.

TEACHING SUGGESTIONS
(pp. 272–273)

● **LESSON:** Why is forest conservation important?

Learnings to Be Developed: Man depends on forests for many products, recreation, homes for wildlife and the prevention of floods.

Developing the Lesson: Allow a reading of the text privately or as a home assignment. Then treat this section on forest conservation as an activity session.

Read Joyce Kilmer's poem "Trees," and discuss its meaning.

Allow groups of children to begin activities such as:

1. On a map of your state, show location of state and national forests and parks.

2. Locate on a map of the United States the leading lumber-producing states. (Listed alphabetically, they are: Alabama, Arkansas, California, Georgia, Idaho, Montana, North Carolina, Oregon, Virginia, Washington.)

3. Build a science picture file on trees. Classify in two groups, coniferous and deciduous.

4. Make a collection of tree products.

Forest Conservation

From our forests come logs for lumber and wood for building materials, pencils, and matches. Rayon, cellulose, alcohol, glue, medicine, and other products come from our forests. Forests also provide recreational areas for people and homes for wildlife. And forests help prevent floods by reducing water runoff.

Each year our forests become more valuable to us. Each year more trees are needed to meet the needs of our growing population. Ways have been found to harvest lumber without doing away with our forests. To do this our forests must be properly managed. Proper management means that the older trees in a forest are cut first. New trees are planted to replace those cut, and these trees are protected from insects, fires, and disease.

FOREST CONSERVATION
Study the pictures carefully and then make up a story to explain each picture. Tell how each picture shows a forest conservation practice. Are you doing your share to conserve our forests?

But proper management of our forests will not protect them from man's carelessness. Each day there are about 500 forest fires in the United States; each year, about 180,000 forest fires. More than 90 per cent of these fires are caused by people. Sometimes a match is carelessly tossed away. Often campfires are not completely put out. It is up to the people who use the woods to prevent forest fires. Do your share: Be careful with fire whenever you visit a forest.

5. Write to American Forest Products Industries, 1816 N. St., N.W., Washington, D.C., 20006, and ask about tree farming and the "Keep America Green" forest-fire-prevention program in your state.

6. Make a list of insects harmful to trees. Learn how they are controlled.

7. Compare slopes in forests and on cleared land. Is there any trace of erosion in the forests? On the cleared land?

8. Make bar, line, and circle graphs showing states leading in production of lumber, pulp and paper, plywood, and furniture; the number of forest fires in your state over the past 5 years; causes of forest fires in the nation.

9. Design a mural on the forest and its uses. Use large sheets of wrapping paper and tempera paint.

10. Write a list of the various trees in your community. Tell how you recognize each one.

11. Examine the layers and rings of a tree that has been cut down. Count rings to determine age. Find out the functions performed by the inner and outer layers of bark, the sapwood, and the heartwood in the living tree.

(pp. 274–276)

LESSON: What is the difference between pure air and polluted air?

Learnings to Be Developed:

Air is a mixture of gases and suspended solids.

Clean or pure air contains oxygen, nitrogen, and a very small amount of other gases.

Polluted air contains larger quantities of other gases, many of which are harmful to life.

Air pollution is increasing as technology increases.

Developing the Lesson: Recall previous learnings concerning the composition of air.

Can you name some of the gases that make up the atmosphere? (Oxygen, nitrogen, carbon dioxide, and water vapor are the normal gases. Traces of the following rare gases can be found in pure air: ozone, neon, argon, hydrogen, helium, and krypton.)

About what percentage of free oxygen is found in the normal atmosphere? (20–21 per cent. "Free" oxygen means oxygen not in compounds such as carbon dioxide or water.)

In some parts of our country, smokestacks such as these pour forth pollutants into the air we breathe 24 hours a day. What role must the public play in seeing to it that our air is clean?

Conserving Our Air

There is poison in the sky. This poison is **polluted air.** At times we can see it—a grayish smoke that hangs over the land, hiding the sun. We can also smell and feel it. Polluted air stings our noses, burns our eyes, and scratches at our throats and lungs.

After a while it seems to disappear, and our skies are once more clear. But it leaves its marks. Plants may be wilted, cattle and other livestock may be ill, plant leaves become coated with a glaze, crops such as lettuce, beans, and alfalfa are damaged, metal is corroded, stone and paint are eaten away, and people suffer with a lingering cough.

If the polluted air settles low over the ground, visibility is reduced and traffic hazards are produced for automobiles and airplanes. Doctors say that polluted air can aggravate heart and respiratory conditions.

Man is responsible for polluted air. Anything that pollutes the air is called a **pollutant.** The great number of industries created by man pour great amounts of pollutants into the sky each day. Fumes from steel mills, power plants, and petroleum and chemical plants often cover dozens of square miles with clouds of black smoke. Exhaust fumes from cars and trucks and buses add to the pollution in the sky. Even the burning of leaves in the backyard sends pollutants into the air.

Whether the pollutants in the air will be dangerous depends on the weather. Usually winds blow the pollutants in the air over mountains, across seas, and over unpopulated stretches of the earth. Snow and rain wash the air clean, washing the pollutants down to the earth. But sometimes there is no movement of air. This happens when a blanket of warm air lies over cooler air near the surface of the earth. This condition may last a few hours, a few days, or even longer before a wind blows the warm air away. There are times when smoke and fog form a mixture called **smog.**

In December, 1962, the city of London, England, was covered by a blanket of gray-brown smog that slowed traffic, made seeing difficult, and darkened the sky. In the four days before winds finally moved the smog, more than 700 people had lost their lives because of it. New York had a similar experience in 1953, and 240 people died as a result of the smog.

The London smog of December 1962 made it difficult to see all but close objects. People covered their faces with scarves or special masks to keep out the dirt and chemicals the air contained. Below, smog covers a major city in the United States.

Of what importance to life are the main gases of the air? (Oxygen is needed by all plant and animal life; nitrogen dilutes oxygen to control oxidation. Carbon dioxide provides plants with needed raw material. Water vapor is needed to complete the water cycle and assist in food production in plants.)

Review by discussion the ideas of gas exchange when only plants, animals, and primitive man were on the planet. Only small amounts of carbon dioxide and other waste gases permeated the atmosphere, but these were gradually used in the recurring cycles. Discuss man's technological improvements over the past century or so.

What improvements in man's living conditions change the composition of the atmosphere? (Combustion engines — autos, steam and diesel trains, buses, trucks, jet planes; homes — gas stoves, oil furnaces; factories — increased burning of petroleum fuels and gas by-products in the chemical industries; atomic energy—fallout contaminants from explosions and testing; rocketry — exotic fuels and exhaust.)

America and Europe have been ahead of the world in the number of automobiles and have the highest number of automobile owners (400 for every 1,000 people).

- *What would be the effect on the atmosphere if 1 billion people of Russia and China were to own autos?* (A tremendous increase in pollution.)
- *What pollutants are found in the atmosphere?* (Increased amounts of carbon dioxide and carbon monoxide, sulfur particles, dust, carbon, pollen, and chlorine, most of which are harmful to life.)

ADDITIONAL ACTIVITIES:

The pupils can see the solids in the atmosphere. In a darkened classroom or other inside area, shine a movie projector or filmstrip projector onto a darkened or subdued wall or blackboard. Have children see the beam of light. The beam is visible because of suspended particles that reflect the light. If the room is really dusty, individual particles can be readily seen.

Place a clean pail or other container, half full of water, in an unprotected outdoor spot about 3 or 4 feet above the ground. Check at the end of 24 hours and again at the end of a week for evidences of foreign matter. This will be a rough measure of the air pollution in your locality.

In 1946, smog covers a tunnel opening in Philadelphia. You see the same tunnel in 1956, after smoke-control measures were taken to reduce air pollution.

The Division of Air Pollution of the United States Public Health Service and city and state departments of air pollution are trying to combat this problem. Congress has made federal funds available to state and local air pollution control agencies for research.

Many industries have changed to fuels which have very little pollutant-creating material in them. Filters have been installed to prevent dangerous material from escaping. Laws have been passed to stop the burning of trash and leaves in backyard incinerators.

The United States Weather Bureau and the Public Health Service have set up the National Air Stagnation Alert System. This nationwide network operates on an around-the-clock basis, recording weather conditions that might favor the accumulation of air pollutants. The records of weather conditions are analyzed, and warnings are sent to areas that might be in danger of hazardous pollution.

Conserving the purity of the air is one of the most important problems in our country today.

To study the sources of contamination, the class can collect dramatic pictures from magazines showing visible air contaminants. They should include forest fires, building fires, auto exhausts, erupting and smoking volcanoes, leaf and trash burning, etc.

Conserving Our Wildlife

You will never see the animals pictured on this page alive. Today you can see them only in photographs and in museums. Not too long ago, however, large numbers of these animals lived. People thought that no matter how many were killed, there would always be more. No record was kept of the number of animals killed. Because of man's carelessness, these animals are **extinct**—they no longer exist.

Many kinds of animals are on the verge of extinction. Many of these animals, such as the whooping crane, of which there are less than fifty in the world, are being protected from extinction by the government.

EXTINCT ANIMALS

Great auk

Passenger pigeon

Eskimo curlew

Labrador ducks

Paroquet

Heath hen

TEACHING SUGGESTIONS
(p. 277)

Background: The balance of nature requires that plant and animal life work for their mutual biological advantage. When one or more species are in danger of extinction, then the balance is destroyed. Man's intelligence makes him responsible for his actions. When he disturbs some part of nature he must compensate for the disturbance.

There are many organizations that can supply teachers with information on wildlife. A few are given here.

American Nature Association, 1214 Sixteenth St., N.W., Washington, D.C., 20006.

Animal Welfare Institute, 22 East Seventh St., New York, N.Y., 10003

Fish and Wildlife Service, U.S. Department of Interior, Washington, D.C., 20025.

Forest Service, Education Section, U.S. Department of Agriculture, Washington, D.C., 20025.

National Wildlife Federation, Educational Service, 232 Carroll St., N.W., Washington, D.C., 20012.

American Forestry Association, 919 Seventeenth St., N.W., Washington, D.C., 20006.

TEACHING SUGGESTIONS
(pp. 278–289)

Background: Beginning on page 279 is an eight-page picture story illustrating some of the many aspects of the United States government's program in conservation. The story may serve as an impetus to discuss the need for conservation measures on the part of our citizenry. The work shown will serve to reinforce many of the learnings developed in previous pages.

Before you begin this section, you may want to send for pamphlets published by various governmental agencies, which will give you additional background information on the government's program in conservation. Below are listed two agencies that supply free pamphlets:

U.S. Department of Agriculture, Washington, D.C., 20025. Send to the Forest Service and Soil Conservation Service, both divisions of the Dept. of Agriculture, and ask for their publications and film lists on conservation practices.

The condor is a bird with a wingspread of over eleven feet. Early pioneers of America, such as those with the Lewis and Clark expedition, called it the "royal vulture." Indians called it the "thunderbird," because they thought that the flapping of its wings made thunder. A hundred years ago there were countless condors. Fifteen years ago there were only sixty. Today there are only forty. The disappearance of the condors is the fault of irresponsible hunters who are killing them faster than they can reproduce.

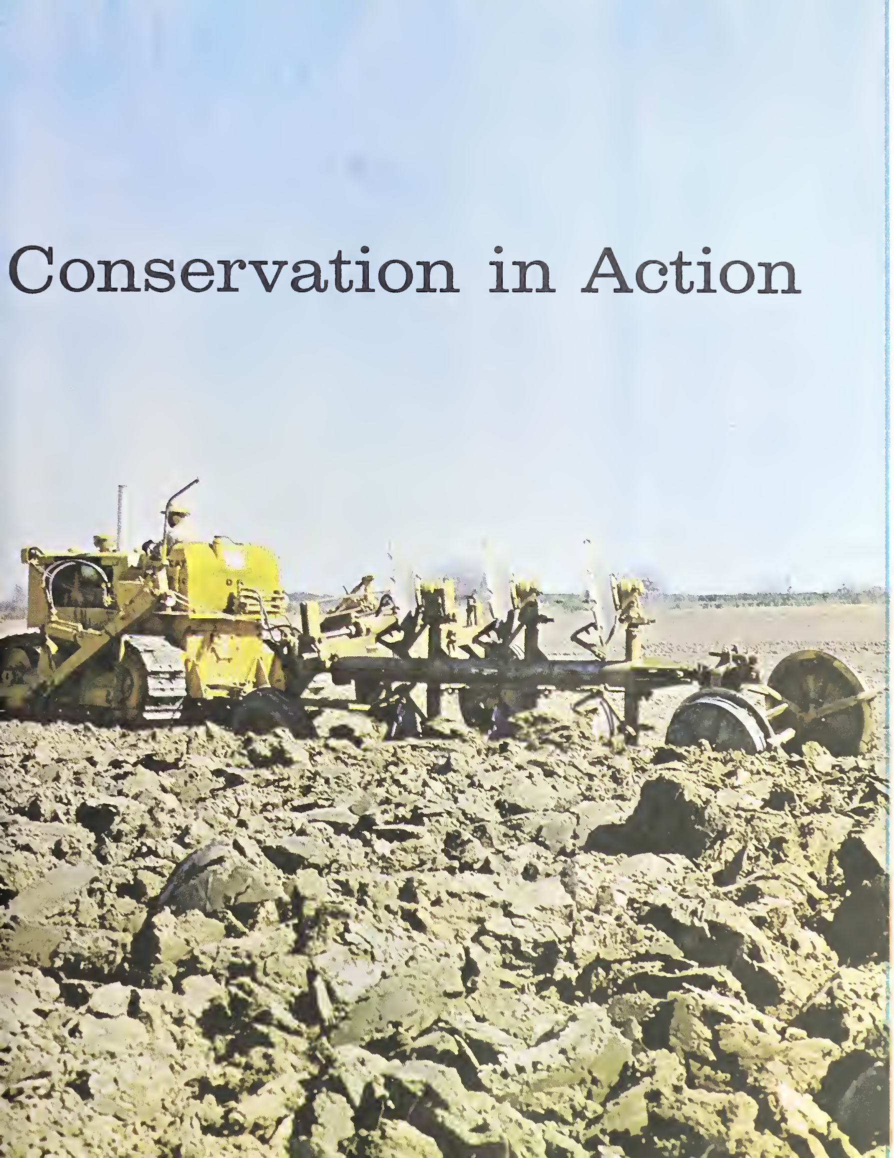
In 1964 a national effort to save the giant California condor was started by the National Audubon Society. The Society, which helped to save eagles from extinction shortly after 1900 and is currently trying to preserve the few remaining whooping cranes, has set up a five-point program to save the condor.

1. It will try to have present laws against killing condors better enforced.
2. It will employ special condor wardens to patrol the lands on which the condors live.
3. It will start an education program for the public.
4. It will set up protective zones around the lands on which the condors live.
5. It will urge various agencies to avoid the use of chemical pesticides that might kill the birds.

ABOUT "CONSERVATION IN ACTION"

The United States government is concerned with the management, conservation, and development of the nation's water, fish, forest, wildlife, mineral, and park and recreational resources. It works to assure that nonrenewable resources are developed and used wisely — now and in the future. In this picture story you will see and read about the United States' conservation program in action.

Conservation in Action



U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., 20025.

These pages present one or more agencies of the federal government in operation. The responsibility for conservation falls to a great extent within the jurisdiction of two federal cabinet departments: the Department of Agriculture and the Department of the Interior. Both of these departments maintain bureaus the children should know about.

The Department of the Interior is charged in general with "formulating and administering programs for the management, conservation, and development of material resources." Its major concern in conservation is with publicly owned lands.

National Park Service: The fundamental objective of the National Park Service is to promote and regulate the use of national parks and monuments in order to conserve the scenery and the wildlife, and to provide for the enjoyment

of these features by such means as will leave them unimpaired for the enjoyment of future generations.

Bureau of Land Management: This bureau administers functions concerned with the disposal of public lands and the development, conservation, protection, and utilization of the natural resources of public lands as well as the mineral resources of some acquired private lands.

Bureau of Reclamation: This bureau attempts a twofold project to reclaim useless land. Transformation of arid land into useful agricultural land through irrigation is one aspect of its work. The prevention of regression to desert land in threatened areas is another. Dam site construction is a concern of this bureau.

United States Fish and Wildlife Service: The service arm of the Department of the Interior is concerned with both commercial and sport fishing.

The Office of Saline Water: This office serves as a clearing house and research center for the desalinization projects of federal and state units. Its major aim is the de-

WILDLIFE REFUGES

The United States government has set aside millions of acres of land to be used as wildlife refuges.

Hundreds of birds flock to the Bear River Migratory Bird Refuge, in Utah. Here they are protected so that they will increase in number and spread to surrounding areas.

Another refuge is Wichita Mountains National Wildlife Refuge, in Oklahoma, where bison protected from hunters roam on vast areas of land.

This is another bison refuge, in Montana, operated by the Department of the Interior's Fish and Wildlife Service.

A refuge manager's job is to make sure that the wildlife is protected. He sees to it that there is enough food and shelter for the animals to raise their young and that hunters do not unlawfully hunt animals on the refuge. Here you see a refuge manager stocking a container with leaflets to inform visitors about the refuge.

Water control is one of the Fish and Wildlife Department's responsibilities. Here two employees are checking a water control structure.

Banding birds such as ducks is also a job of those who work on refuges.

Thousands of people each year visit the refuges. In this picture, you see a manager holding a rattlesnake at bay during an Audubon Society visit.

Fishing is permitted on many refuges.

Fish derby catches are weighed at Tishomingo National Wildlife Refuge in Oklahoma.

velopment of practical means for the economical production of water for industry, agriculture, and municipal use from the sea.

Forest Service: The Forest Service is charged with the responsibility for promoting the conservation and best use of the nation's forest lands—about one-third of the land area of the United States.

The Forest Service administers 154 national forests. It improves these lands, protects them from fire, insects, and disease, and manages the resources that are of economic value. The national forests are managed under a twin conservation policy of multiple use and sustained yield. Livestock grazing on certain grasslands is scientifically regulated to attain range conservation along with use of the annual growth of forage. Watersheds are managed for regulation of stream flows to reduce the danger of flood and soil erosion. Technical methods of forestry are applied to the growing and harvesting of timber.

Your students may wish to become Junior Forest Rangers. If so, simply have them request the Forest Service to send them badges and certificate.

Soil Conservation Service: The SCS provides technical assistance to all concerned agencies of the state and local governments as well as to individual farmers on their needs involving soil management, chemistry, watershed protection, and flood prevention. In addition the SCS makes and coordinates snow surveys for water forecasting in the western states.

It assists the *Farmers Home Administration* by providing technical information regarding loans for soil and water conservation projects on private lands.

The *Agricultural Stabilization and Conservation Service* is concerned with the conservation needs of food commodities and prepares detailed lists of acreage to be diverted to new food-producing crops. Its major concern is the farmer.

The National Agricultural Library has resources of almost 1,200,000 volumes on agricultural topics. It is the second largest U.S. government library in existence and the largest agricultural library in the United States.

FISH HATCHERIES

More than one hundred National Fish Hatcheries operated by the Fish and Wildlife Service are located throughout the country to help manage our important sport and commercial fishing resources.

Hatcheries raise the kinds of fish that are most needed for fishery resources in the area. This is Spring Creek National Fish Hatchery in Washington.

This is the Edenton National Fish Hatchery in North Carolina. It is a pondfish hatchery. It produces largemouth bass, bluegill and channel catfish, and other warm-water fish. The ponds are each fertilized, and in this picture you can see different stages of plankton growth. Which areas have the most plankton? How can you tell?

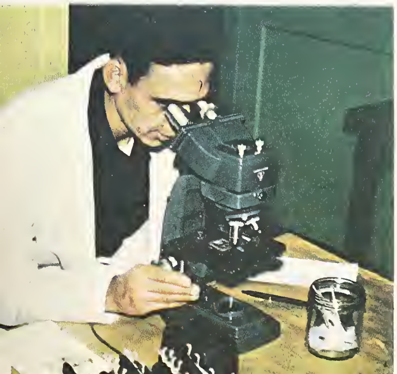
Here the eggs are being gently stripped from a female rainbow trout while milt is added from the male. What does the milt do?

Here you see newly hatched trout living on nutrients drawn from their attached yolk sacs.

Fish are weighed before being released to a farm fishpond.

Trout are stocked in public fishing waters in a National Forest.

Insulated tank trucks carry large loads of live fish great distances with safety.



Fishery biologists check fish at the hatcheries for disease.

Information contained in the library's collection is distributed through loans, photocopies, reference services, and bibliographies. These services are made available to anyone, both in the United States and abroad.

Films:

Conservation Films. Since most schools are not in a position to have their classes visit wildlife areas, national forests, large virgin marshlands or wildlife preserves, we have listed some films that will provide a vicarious field trip. Where field trips are not possible, filmed trips provide expert guides, emphasis on the most significant features, and an economy of time.

The following films are suitable for children in the sixth grade:

Quetico (22 minutes, color, sound, Contemporary). With a minimum of narration the picture tells its own story about the significance of wilderness. The feeling of respect for nature emerges eloquently without words, directly through the sensitive photography.

Big Risk (22 minutes, color, sound, Modern). The oil industry's search

for new reserves of its raw material is dramatized in this Ohio Oil Company production. Excellent photography featuring Guatemalan surroundings makes an attractive introduction to the problem of finding new sources of nonrenewable resources. An unusually attractive example of a commercial film.

The Window (17 minutes, color, sound, Audubon). This film emphasizes that classroom experience is not enough—that students need outside learning activities. Not the least of the values is that the script reveals that discovery of the natural world at a child's own doorstep can also mean discovery of himself.

Beach Hike (17 minutes, color, sound, Northern). Here is a literal documentation of a 20-mile, 3-day hike along the rugged shoreline of the Olympic National Park. The leader of this nature hike is Justice William O. Douglas of the United States Supreme Court. He notes that a through highway parallels all but 20 miles of the park's shoreline. "Do roads have to go everywhere?" he asks. "Does the whole wilderness have to be paved"?

FOREST CONSERVATION

The United States has about 182 million acres of valuable forests. These public forest lands are scattered from Puerto Rico to Alaska. These are our National Forests. National Forests provide not only timber but also protection for the watersheds of streams. They also provide food for livestock, homes and food for wildlife, and recreational facilities for people. All these resources are managed by Forest Rangers to provide the greatest possible use.

Forest Rangers are trained through college study and practical experience to manage timber, range, water, recreation, and wildlife resources.

Insects and disease kill more trees every year than do fires. Rangers watch for diseases caused by insects and try to prevent them from spreading. One of the most destructive diseases is white pine blister rust. It is controlled by spraying the pines with an antibiotic fungus killer.

This woman serves as lookout during periods of fire danger. If she sees a fire she alerts the Forest Ranger station.

The Forest Rangers are prepared for emergencies such as fires. Modern machinery is immediately put into action.

Airplanes drop a special powder to put out fires.

Helicopters drop loads of water.

Many forest fires are caused by carelessness. If you use our National Forests, be careful — prevent fires!

SOIL CONSERVATION

Soil conservation is another important job of the United States government's conservation program. Here you see some of the work done by the Soil Conservation Service. For more information write to the Department of Agriculture, Soil Conservation Service, Washington, D.C.

Here a soil sample is taken of land on which corn has been grown since 1931. The sample will be examined under a microscope in the laboratory. Why do you think such samples are taken?

The Enduring Wilderness (27 minutes, color, sound, sale only, Sterling). No less than our own country, Canada has expressed deep concern over the need for the preservation and maintenance of its natural beauty. The story, although it chiefly underlines the need for national parks as reserves and sanctuaries in regions now feeling the impact of the population explosion, is important because of the mood it creates.

Life in the Woodlot (17 minutes, color, sound, National Film Board of Canada). The story of the living community of plants and animals unfolds through the eyes of a man who understands and values the woodlot entrusted to his care.

Water (15 minutes, color, sound, Columbia). This film makes the point that today's demands, pollution and waste, and the rapidly expanding population are bringing us to a worldwide water crisis. Since water crosses all barriers, it is suggested that an international organization of nations work out the problem of controlling and planning for water and its uses.

Conservation Vistas (14½ minutes, color, sound, U.S.D.A.). Of partic-

ular interest to teachers beginning work in conservation, this excellent film presents both classroom and outdoor activities designed to arouse children's curiosity and concern about conservation.

The Worlds of Dr. Vishniac (20 minutes, color, sound, Horizons). By emphasizing the human and personal side of microbiologist Dr. Roman Vishniac, this film provides a new angle on the conventional approach to science. Dr. Vishniac explains his equipment, methods, and motivation. The specimens used in his microscopic-photography work are carefully returned to the pond. His explanation that he has only borrowed these animals and must return them before he has the right to take more is only part of the novel approach of this scientific film.

Air Pollution—Everyone's Business (20 minutes, color, sound, Kaiser Steel). This story demonstrates exactly how the ordinary daily activities of many individuals combine to pollute the air. Clear animation illustrates the manner in which air pollutants react with elements such as ozone to create

A gauge to record rain, snow, hail, or sleet is adjusted. The information gained from such gauges is necessary for flood control.

Snow surveys measure how much water runs off the mountains when the winter snow pack melts. This information is needed to predict floods or droughts, to plan for water storage, and to use for irrigation and hydroelectric power. Snow measurements are made by sampling snowfields with a hollow aluminum tube.

The aluminum tube and the snow sample it contains are weighed. From this figure is subtracted the weight of the empty tube. This figure is changed mathematically into inches of water in the snow, and is used to forecast runoff and stream flow.

Snowfields are measured in exactly the same location each time. The location is called a snow course. Why do you think repeat measurements are made year after year in the same place?

You have seen and read about only a few of the activities of the United States government's program in conservation. Use your school or public library to find out more. You will be surprised to find out how many people work at conserving wildlife, land, and water.

There are other groups also working to save animals from extinction. In 1964, when thousands of miles of forests were being flooded by the new Afobaka Dam on the Surinam River in Surinam, South America, a project called Operation Gwamba was begun. Gwamba comes from a phrase in the language of the jungle people meaning "Pity the poor animals." Both the Surinam government and the International Society for the Protection of Animals supported Jan Michels, a Dutch district commissioner, and John D. Walsh, an officer of the Massachusetts Society for the Prevention of Cruelty to Animals, in their project.

Sloths, ocelots, boa constrictors, howler monkeys, and other animals were lassoed from trees or taken from the water. Traveling in canoes and wearing heavy gloves for protection, the two men and about twenty-five helpers, armed with poles that had nooses on the ends, pulled down the animals trapped in the treetops. The animals were tied up with old nylon stockings and then released on the shores of the rising lake.

smog. Although produced and mainly photographed in Los Angeles, the film is applicable to other areas.

ADDITIONAL ACTIVITIES:

In order to build a library of visual aids that is both meaningful and local in perspective, a local group of teachers (science teacher association) or a single class could undertake a long-term project. The project would have as its objective a survey of local county or city conservation problems. The procedure might follow the pattern indicated here or else vary to suit local needs.

Budget needs. Anticipated budgetary needs could be underwritten by a PTA, Kiwanis, Lions, or community service club, or else a local manufacturer of audiovisual equipment.

Survey of conservation needs. Write to and secure interviews with local, state or federal groups in your area:

Department of Public Works
Department of Water Supply
Park Department
Health Department

Planning and Zoning Board
Agricultural Societies
Conservation groups
Highway Departments
Local Bureaus of Federal and State, wildlife, forestry, mines, soil, and water.

A series of questions should be posed to all the above groups:

- *What are the most important problems in your field?*
- *What steps are being taken to solve these problems?*
- *Where may we photograph these problems and/or solutions?*

Technical assistance. Consult the school or district audiovisual coordinator or the high school photography club to learn the best camera procedures for producing clear photographs for reproduction, color slides, transparencies, and enlargements for posters.

Professional help. Most of the photography can be done by amateurs, but the public relations staff of the departments mentioned might be able to provide you with glossy prints which could supplement your own photographs. In most cases the printed pictures in bulletins and brochures are good leads to possible shots, but they will not be useful for audiovisual production.

In Rhodesia, Africa, government game rangers have launched a program to save rhinoceroses from death. Many of the animals have been captured and taken 260 miles on a rough wooden sled to Rhodesia's Wankie Game Park, where they will be protected.

These are just a few of many examples of the efforts of various governments, societies, and individuals to protect living things from extinction. To let any species of plant or animal vanish is to lose for all time a part of our inheritance. The plants and animals alive today are the ancestors of all the plants and animals there will ever be. Extinct species are gone forever and, with them, the offspring they would have had.

You read about the discovery of penicillin when you studied diseases. Until its discovery, few people, including scientists, gave much thought to the fungus organisms living in the soil. Now these organisms are being studied in hundreds of universities, government agencies, and industrial concerns as possible sources of drugs to aid human health. This is an example of how a little-known species of plant can become a valuable contribution to the world. The condor, the whooping crane, the rhinoceros, and the fungus organism are all living resources. It is important for man to protect them. Man's nonliving products can all be replaced, but man can never replace extinct species of living plants and animals.

While many people are aware of what is happening, few do anything about it. Man has a choice: He can conserve his living resources so that they provide a continuing harvest, or he can exhaust them and endanger his own survival. In the years to come, you will have something to say about the choice that must be made.

Conserving Human Resources

You are a resource. Every human being is a resource.

Today polio, smallpox, and other diseases need no longer destroy human lives. Yet many people have diseases that could easily be cured if they were treated by doctors. These diseases make them unable to do any work. In other parts of the world, people lack the skills needed to make enough money to eat properly. In many areas, thousands of people live cramped together in rooms or shacks without water, electricity, or toilets. Tens of thousands of people are unable to use their abilities to their fullest because of the conditions into which they were born. All these people might have something to contribute to our world, but they are unable to. Of all our

resources, human resources are our most precious.

In conserving human resources we must deal with the problems of poverty and ignorance and the danger of using up our resources of food, fuel, living space, and privacy. When any of these resources is inadequate, human energy that might produce great works of art or scientific discoveries is diverted to the problems of day-to-day survival.

In some places, people live cramped together in shacks or boats. They are underfed, poorly clothed, diseased, and unskilled. How might they be helped?

Photographing. Your visits to "location" can be made by assigning committees to work on their own on Saturdays, Sundays and holidays. An occasional trip with the entire group might be profitable. In the beginning such a trip is suggested.

Editing. Prepare to eliminate more than you accept.

Assign groups to evaluate the material for photographic quality, impact, and consistency with the questions asked above.

Assign groups to handle the areas of problems: soil, water, air, trees, wildlife, etc.

Prepare media. Slides, poster photos, transparencies, etc.

Narration. Prepare notes and possible narration to accompany each slide or audiovisual aid.

These suggestions are but an outline. Each one admits of variations and is open to both limitation and expansion. Perseverance is required, but the rewards should be great.

Note: If a teacher group were to undertake such a project, perhaps a local school board or local university might assign in-service or academic credit.

TEACHING SUGGESTIONS
(pp. 290–291)

● **LESSON:** How can human resources be conserved?

Learnings to Be Developed:
Every human being is a resource.

In conserving human resources we must deal with the problems of poverty and ignorance and the danger of using up our resources of food, fuel, living space, and privacy.

Developing the Lesson: Look at the pictures on page 289 and begin your discussion by asking why people who live in the conditions shown may not be able to use their abilities to the fullest.

Relate the conservation of human resources to constructive measures presently at work in the community. Such measures include new housing to replace substandard housing, parks and playgrounds, community recreation centers, street social workers, scholarship plans, antipoverty programs, health centers for free or low-cost medical attention, hospitalization plans, guidance programs, and other programs to conserve human life.

These boys and girls come from many states. They are all winners in a Science Fair contest. They may not all become scientists, but they all understand the importance of science in today's world. Why is this important?

William Vogt, a conservationist, compares the growth of human population with the human pulse rate. If you count your pulse for a few seconds, it will not quite keep up with the increase in world population. Each time your heart beats, more than one human being will have been added to the population of the world. In the past fifty years, the population of the world doubled.

With more people living on the earth, more food, more clothing, more houses, and more forms of transportation are needed. Thus, more of the earth's natural resources are used up.

To conserve our human resources, scientists must find ways to obtain more water, use the soil to greater advantage, and find ways to farm the seas, among other things.

Brainpower has been called our most precious national resource. How well we meet the problems of tomorrow's world depends on how well we discover, encourage, and develop exceptional talent in all fields. The talent of the scientist and the resources of the educated person who can recognize the importance of science for other fields, such as medicine, military affairs, industry, law, and politics, must be conserved.

Teachers and others who work with young people must encourage and guide those who show promise. They must help them seek and obtain the goals for which they are best suited. People are learning to respect intelligence. No one can tell how great a contribution an intelligent person can make.

The guidance counselor helps this girl decide what kind of training she will need for the career she has chosen.

Conservation and You

The world of tomorrow depends on what we do today. If we waste our resources the world may be barren for those who follow us. But if we care about tomorrow we can use what we know to make this a world of plenty. We know much about conserving wild-life, soil, water, and forests. And we know much about conserving human life. All are related. Each depends on the others. Although there is still much to be learned, we know enough now to do something, and we know we must do something. The choice is up to every one of us.

We can send food and clothing to help people. Perhaps, more importantly, we can send trained people to help them learn modern ways of building, working the land, and preparing foods. We can train doctors, teachers, carpenters, and plumbers. In these ways, we can help these peoples to help themselves.

To show that people are resources, try this activity with the class. Ask the pupils to write down on a piece of paper one activity that they take part in during an ordinary day. Next to it write down all the occupations of the people who make possible the activity they chose.

For example, suppose an activity was playing baseball: Who made the ball? Who got the materials to make the ball? Who sold the ball? How did the ball get from the factory to the store? Who built the truck to carry the ball? and so on. Point out that everyone is important. Without the smallest job you would not have a ball.

ADDITIONAL ACTIVITIES:

The work of this unit is as broad as life. You can find many people to come into your classroom to provide interesting background for your teaching—county agents, foresters, biology professors, museum curators, etc.

If your school is near a bird sanctuary, an experimental farm, a fish hatchery, or a laboratory that contributes in some way to conservation, try to plan a visit to the place with the class.

TEACHING SUGGESTIONS
(pp. 292–293)

Background: The answers to *Using What You Have Learned* are:

1. Answers will vary according to locally. Insect life and lower animals should be pointed out.

2. Need for balance in nature should be emphasized.

4. Man has a social conscience. His use of his own property should not be such as to harm others. Ownership of an automobile does not give the right to speed. Ownership of a gun does not allow indiscriminate use. Ownership of land, water, or wildlife does not give the right to ignore the needs of others who may depend on them.

7. a. Some states have laws protecting birds by outlawing the use of feathers for decorative purposes. Other birds are protected by national laws.

b. Bison were killed as a food staple for the railroad builders.

c. Some dams eliminated salmon spawning grounds in the Pacific Northwest. Others provided alternate ladder routes for the salmon to pass upstream.

8. Some common crop rotations: Rotation of crops is used for weed control, erosion prevention, in-

Using What You Have Learned

1. Make a list of all the different kinds of animals you can find in an empty lot near your home. What happens to each animal when a house is built on the lot?

2. Make a plan for helping other children in your school find out about the usefulness of wildlife. What different kinds of posters could you make? What kind of talks could you give? Could you write a short play about wildlife for an assembly program? Your class might prepare an exhibit on the usefulness of wildlife.

3. Find out from some of the people who have lived in your community for many years what animals used to be more common where you live. What has happened to these animals?

4. Why should everyone not be allowed to use the wildlife that lives on his own property in any way he wants to?

5. What are some of the hunting and fishing laws in your state? Discuss the reasons for these laws.

6. Write to your State Conservation Department. Ask for pamphlets about animals that are protected in your state. Find out how these animals are protected. Is your State Conservation Department trying to cut down the number of any animals? Why?

7. Look up one of these subjects and report about it. You may have to look in several different books.

a. The use of bird feathers for ornaments
b. How railroads affected bison
c. How building dams on certain rivers has affected our supply of salmon

8. If you live in a farm region, ask some farmers about the

crop rotation plans being used locally. Find out why they use this particular method.

9. Make a map showing the sources and location of various types of water pollution in your area. Find out from county, city, and state officials what is being done to decrease pollution. Make a sand table model to show how water pollution occurs.

10. Take a census of trees along the sidewalks in your community. Since you may not be able to count all the trees, do it this way. Have each pupil in your classroom count the number of trees of all kinds there are along the block where he lives. Next, figure out the number of tree-lined blocks in your community. Now can you figure out how many trees there are along the walks in your community?

11. Explore an empty lot or field near your school to find out what food wildlife of different kinds could find there. Look for seeds and for insects, worms, and other small animals. If you live near a woods, explore it in the same way. Compare the woods and the empty lot as wildlife refuges.

12. Theodore Roosevelt did much to protect wildlife when he was President. Read what he did in a biography of his life or in an encyclopedia.

13. Find out what your community is doing about air pollution.

14. Discuss with your class why we cannot afford to waste human resources. Find out what your community is doing to conserve human resources.

15. Write a report on John James Audubon, whose 435 paintings are known the world over for their naturalness and accuracy.

16. Find out why Alexander Wilson is known as "the father of American ornithology."

sect control, and soil fertility, but not all at the same time. For example, Peanuts, cotton, and tobacco are planted in a 3-year sequence of rotation to discourage root diseases.

9. Common water pollutants: cesspools, sewage, industrial wastes, stagnant ponds.

14. Youth agencies, YMCA and YMHA, C.Y.O., welfare agencies, Boy Scouts, and service clubs are all possible sources of information. National programs such as "Head Start," anti-poverty programs, and the Peace Corps also contribute.

16. Alexander Wilson (1766–1813) was a rural teacher in New Jersey and Pennsylvania. He studied bird life and drew local birds. He composed the first complete study of the birds of America: *American Ornithology* (9 vols.).

TEACHING SUGGESTIONS
(pp. 294–295)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned: This is a summary of the entire unit, with new words in boldface type.

WHAT YOU KNOW ABOUT

Life on the Earth

What You Have Learned

All living things get food from green plants or from animals that eat green plants. Green plants take in water, carbon dioxide, oxygen, and minerals. They use light to change these substances into glucose by the process of photosynthesis, which takes place in the parts of the plant cells called **chloroplasts,** which contain the green chemical **chlorophyll.**

Some plants help make soil. **Lichens** are plants that grow on rocks. They use oxygen and give off carbon dioxide, which combines with water to form **carbonic acid.** This acid slowly eats into the rocks and makes cracks in them. Roots of lichens and mosses grow in the cracks of the rocks and split apart the rocks to form the soil.

There are different kinds of regions on earth—deserts, mountains, grasslands, and forests. Each has its own kinds of plant and animal life best adapted to the environment in which they live.

When environmental conditions change, the animals and plants must adapt themselves to the new conditions or die. Some animals adapt to winter by **hibernating.** Other animals **migrate** to a warmer place for winter.

There is a natural balance or interdependence among all living things. Whenever the natural balance is upset, some living things die. **Predators** are animals that attack other animals for food, creating a natural balance of life between two or more different animal populations.

Man sometimes upsets the balance of nature. To preserve the natural balance of life, man must carefully provide for the protection and **conservation** of the earth's resources.

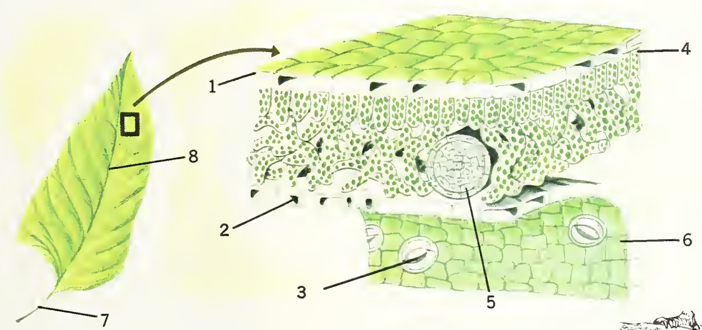
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

biochemists	extinct	predators
carbonic acid	hibernation	protective coloration
chloroplasts	migration	smog
conservation	pollutant	stomata
epidermis		

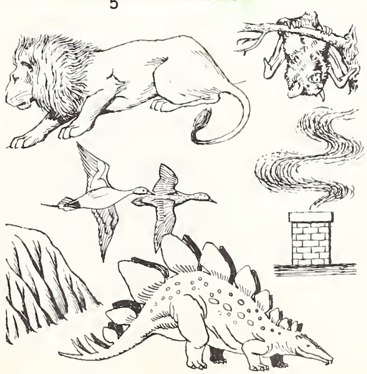
Can You Identify the Parts?

Look at the diagram of a green plant. In your notebook write the numbers 1 through 8. Next to each number write the name of the part shown.



Fill in the Missing Letters

This animal is a p_ _ _ _ _ _ _.
This animal h_ _ _ _ _ _ _ _ _ _ in the winter.
This animal m_ _ _ _ _ _ _ in the winter.
This air is p_ _ _ _ _ _ _.
This soil is e_ _ _ _ _.
This animal is e_ _ _ _ _ _.



Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390–393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

Can You Identify the Parts?

1. Upper epidermus
2. Lower epidermus
3. Stomate
4. Chloroplast
5. Vein
6. Cell
7. Stem
8. Vein

Fill In the Missing Letters:

predator
hibernates
migrates
polluted
eroded
extinct

TEACHING SUGGESTIONS
(pp. 296–297)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

A biome is a large geographical region identified mainly by its climax vegetation. For examples: coniferous, deciduous, desert, fresh-water, grassland, marine, rain forest and tundra.

You Can Make a Biome:

1. Observation over a period of time should give a basis for responses.

2. Algae and elodea manfacture food by photosynthesis. The raw materials (calcium salts, water, carbon dioxide) come from dissolved molecules in the environmental water. The guppy gets its food from small animals in pond water (protozoa). The snail utilizes the wastes of the fish and small animals. Protozoa devour algae and other protozoa.

3. Energy is released in their body cells by the burning of stored chemicals — mainly sugars and starches.

4. The sun provides the energy for the main steps in the photosynthetic process.

YOU CAN LEARN MORE ABOUT

Life on the Earth

You Can Visit a Biome

A biome is a community of living things that depend on one another for survival. A good biome has a variety of land forms and different kinds of plants. A biome may be a forest, a pond, a desert, an open field, a meadow, or any other natural environment.

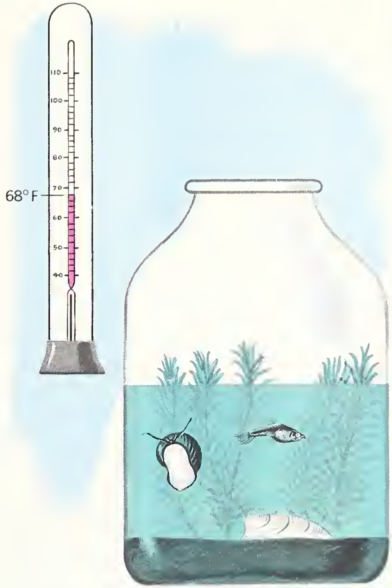
When you visit a biome, answer these questions:

1. Where do you find various plants?
2. Where is there water?
3. Which areas get the most sunlight?
4. Which areas get the least sunlight?
5. What does the amount of sunlight have to do with the location of the plants found?
6. How do the plants affect the temperature?
7. What relationships do you find between plants and kinds of soil?
8. Do you find any eroded land?
9. What signs do you find of animal life?
10. Do you find any animal life living on plants?
11. How do these animals differ from animals that do not live on plants?

You Can Make a Biome

Fill a three-gallon bottle halfway with pond water. Then add about ten ounces of soil and some algae from a pond. When the water is clear, add five sprigs of elodea. Next, place a guppy, a snail, and a piece of clamshell in the bottle. Place it in a well-lighted part of your room, but not in direct sunshine. The temperature should not rise above 70° F.

1. How does this biome show the interdependence of the plants and animals in it?
2. How does each organism get the food it needs?
3. How do the animals get their energy?
4. How do the plants get the energy they use in photosynthesis?
5. How do the plants get the energy for their life processes other than photosynthesis?



You Can Read

1. *The Tale of a Pond,* by Henry B. Kane. Describes a cycle of life in a pond.
2. *The Web of Nature,* by Ted S. Pettit. A description of various kinds of environments and the need for conservation practices.
3. *The First Book of Conservation,* by F.C. Smith. Discusses the interdependence of living things, how man has upset the balance, and practices to conserve our natural resources.

5. Plants use the stored energy in chemical nutrients, initiated by photosynthesis, to carry on all other life processes.

You Can Read: Some possible teacher references are:

Teaching Science Through Conservation, by Paul F. Brandwein, (McGraw-Hill, 1960). An excellent sourcebook for the rationale and need for conservation in science education. It offers myriad projects, experiments, and activities.

Everybody's Riches, by Grace Brown and Guy H. Browning (Century Schoolbook Press, 1959). The teacher's edition contains much of interest and use.

Animal Diversity, by Earl D. Hanson (Prentice-Hall, 1961).

The Big City Book of Conservation, by Catherine Urel et al. (Follett, 1956).

U.S. Department of Agriculture *Yearbooks,* available from the Government Printing Office. The most useful in conservation are: *Trees* (1949), *Insects* (1952), *Water* (1955), *Soil* (1957), *Seeds* (1961), *A Place to Live* (1963), and *Farmer's World* (1964).

The Conservation Handbook, ed. by Richard Weaver (Interstate Printers and Publishers, Danville, Illinois, 1958).

KEY CONCEPTS

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 2. Lawful change is characteristic of events in the natural environment; although living things tend to produce living things like themselves, over millions of years the earth and living things on the earth have changed, and diversified forms of life have evolved.

Key Concept 3. To find order in the natural environment, the scientist seeks basic units that can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.

Key Concept 7. When equilibrium is upset in organism-environment interactions, regulatory mechanisms go to work to restore equilibrium.

Key Concept 8. There is a relationship between structure and function; the structure of parts of living organisms determines the function of those parts.

8

Other concepts appear under "Learnings to Be Developed in each lesson found in the Teaching Suggestions.

How Animals Behave

Observing Animals

Animal Sense Organs

Explaining Behavior

Is Animal Behavior Inherited or Learned?

CONCEPTS:

1. Scientists are learning about the behavior of animals through careful observations of them under controlled conditions; they look for relationships between observed behavior and conditions under which it occurs.
2. Scientists attempt to develop ideas about animal behavior that will apply to many animals.
3. Animals respond to environmental conditions only as they sense the conditions.
4. Animals adjust to changes in their environment.
5. There is a significant relationship between the structures of animals and their behavior.

PROCESSES:

- Observing—Pages 306, 307, 308, 313, 318, 321, 324, 329, 330.
- Experimenting—313, 318, 321, 324, 329, 330.
- Comparing—306, 307, 308, 313, 318, 321, 324, 329, 330.
- Inferring—306, 307, 308, 313, 318, 321, 324, 329, 330.
- Measuring—329.
- Selecting—311, 315, 336, 339.
- Communicating—339.
- Demonstrating—302, 324.
- Explaining—306, 307, 308, 315, 320, 321, 335.
- Hypothesizing—314.

TEACHING SUGGESTIONS
(pp. 300–305)

● **LESSON:** Why do we observe animal behavior?

Background: Many of our past errors in explaining biological activities of animals can be attributed to our tendency to explain them in terms of human motives. Plants don't "bend to the sun to get more light." While the phenomenon is correctly described, it sometimes leave the wrong idea of motivation. If an animal such as a spider builds a web "in order to trap insects," it must be kept in mind that the spider does not have intentions.

The tendency to describe animal actions in human terms is called *anthropomorphism*. Where possible, it should be avoided.

Learnings to Be Developed:

Scientists who study the behavior of animals are called *ethologists*.

The ethologist assumes that the behavior of animals is the result of an interaction between a stimulus in the environment and the nature of the animal; he searches for the particular stimulus that might set off a reaction.

Developing the Lesson: Introduce the unit by incorporating some of the ideas introduced in the material

There is a legend that King Solomon had a magic ring. With it he could speak to animals. He could understand them and, in turn, be understood by them. You need not have a magic ring to understand living things. You can learn about them by observing and studying the ways in which they behave.

Observing Animals

When your parents talk about your behavior, they usually mean something you did that was good or bad. When a scientist talks about behavior, he means all the *activities* of an animal except those that it is born with and that are automatic, like breathing. Have you ever turned a beetle or an ant from its path as it marched along a tree trunk? Did you observe what it did to find the path again? You were studying the beetle's or the ant's behavior. Scientists study animal behavior to try to explain how and why animals do what they do.

If you drop some food into an aquarium, a hungry fish will go after it. Notice that the fish does not swim around in circles searching for the food; it swims directly to it. Try fooling the fish by dropping something into the tank that looks like fish food but is not, and you will see the fish swim away from it. Some people explain the fish's behavior by saying, "It was born that way," or, "It can think and figure out the difference." But animal behavior is much more complicated, as you will see.

To start your study of animal behavior, you must observe animals carefully to see exactly what they do. If you have a pet at home, you can start by observing its behavior. You can also observe the birds and squirrels in your backyard or park. You can find insects for study almost anywhere, both inside and outside.

Snakes, frogs, and toads are easy to catch. Search the ponds and streams near your home for fish and other water animals. Catch some with a net and bring them to your school or your home for study.

If you live on a farm, you will have many opportunities to observe animals. Finding an animal to study should be easy for everyone.

Birdwatching is for both young and old. Studying the behavior of birds will give you many hours of pleasure and may develop into a lifetime hobby.

Describing Behavior

When you first try to observe animal behavior carefully, you may find that you have never *really* looked at what an animal does. You know that your dog or cat or hamster eats, moves about, makes noises, and has some funny habits, but chances are that you have not really noticed its behavior.

Scientists who study the behavior of animals are called **ethologists** (eh-THOL-uh-jists). An ethologist is curious about every detail of behavior. To organize his study, he classifies the many different kinds of behavior under headings such as "food-getting," "fighting and escape," and "moving about." He wants to know why an animal eats what it eats and when it eats. He wants to know what an animal will do if a stranger approaches. He is curious about how an animal finds its way and why it does not lose its way. He may study an animal in its natural environment, or he may bring it into his laboratory.

on pages 298–299. Borrow for the occasion, if the class does not have one already, a pet hamster, bird, guinea pig, white mouse, or similar small animal, properly caged. More exotic pets may be available, but be sure you know the safety and health rules concerning the animal when introducing it to the pupils—*and observe the rules yourself!*

Before reading the observations on the stickleback (p. 302 ff), center discussion around your classroom pet by such questions as:

- *Does the animal cower or seem to be afraid of the class?*
- *Is it trembling or giving any indication of being upset over class attentions?*
- *Do you think it would eat some food if made available?* (Proceed to feed and observe — the animal's actions at this point should suggest other questions.)
- *What position is the animal in when it eats?*
- *Does it hide the food in a particular section of the cage or eat it immediately?*
- *Does it have a pouch for storing uneaten food?*

Observe other kinds of behavior:

- *Do loud sounds affect the animal?*
- *What happens when a bright light is brought near?*

Observe the structure of the animal's body.

- *How would you describe the animal's ears? Eyes? Feet? Tail? Mouth?*
- *What changes take place when the animal walks? Climbs? Jumps?*

At this point a change of view could be introduced, such as:

- *Do you think that bird is aware that it must clutch a branch and tighten its grip in order to stay on?*
- *Are you aware of the actions of your muscles when you stand?*

Emphasize that some actions are conscious and some are not. A child must learn to walk, but not to breathe and swallow. We learn how to hold a spoon, but not how to sneeze.

Our observations and study of animals will help us to understand these and similar kinds of behavior better.

Follow-Up: Encourage children to care for and study a pet. Most pet

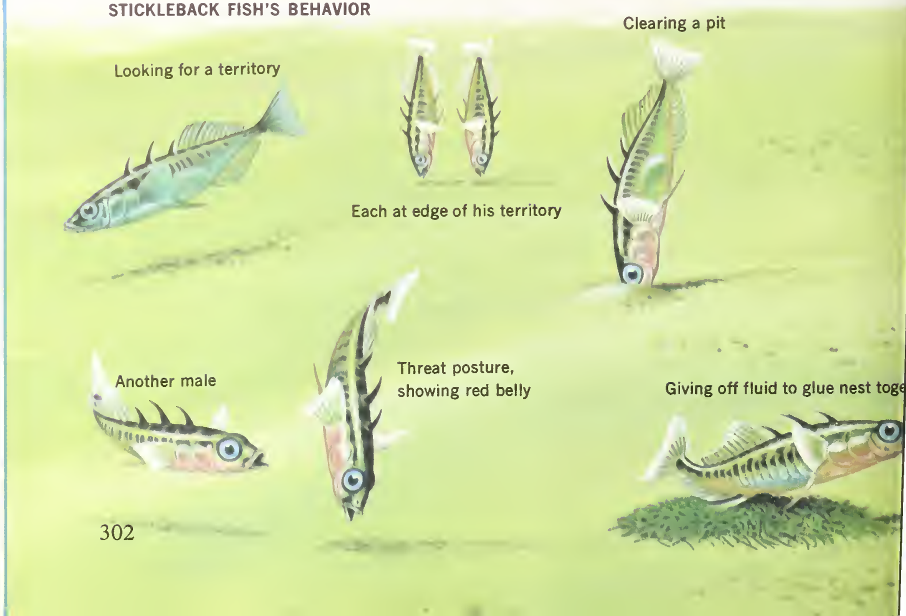
As the ethologist observes, he searches for clues that will lead to ideas that will help him to describe and explain behavior—ideas that will explain many different situations. These are *key* ideas. The fact that your dog barks every time the doorbell rings is not really a key idea; it does not explain very much. On the other hand, the ethologist, for example, is interested in explaining what makes animals ready to fight and why they are more ready at some times than at others. He is not satisfied to know simply *that* they fight. How do you think the ethologist goes about his work?

To find the key ideas about fighting behavior, the ethologist can start with almost any animal that can fight. He knows from previous research—his own and the research of others—that certain things will be true of all fighting animals, even though the *details* will be different. A dog fights differently than a cat, but some things about their fighting are the same.

Observing the Behavior of the Stickleback Fish

One animal whose fighting behavior has been studied in the search for key ideas is the stickleback fish. This is

STICKLEBACK FISH'S BEHAVIOR



a rather common fish. If you have ever caught this fish with sharp, spiny sides, you know that it is a fighter. The stickleback not only is a fighter at the end of a fishing line; it is a fighter in the water, too. Thus the stickleback fish is a good subject for the ethologist to study.

As the scientist observes the stickleback, he finds that it is the male that fights. But even the male stickleback does not fight all the time, and he fights more fiercely at some times than at others. After more observations, it is found that the stickleback does most of his fighting right after he has built his nest. This is also the time of his fiercest fighting. If a stranger comes close to his nest, the male stickleback fish charges with great speed and fury. He fights even if the stranger is much larger than he is. He extends his spiny sides and dashes at the enemy, chasing him away fast and furiously.

The ethologist uses other information to help him understand the behavior of the stickleback.

Knowing that fighting is related to nest building, the ethologist records observations when the stickleback starts building his nest. He finds that the stickleback builds himself a nest at the

stores can assist in suggesting inexpensive pet hobbies. Some of them are even profitable.

During this unit, maintain daily anecdotal observations of a class pet. Keep a regular schedule for feeding and for cleaning the pets quarters. Provide adequate caging, for the safety of both the children and the animal. Secure a pamphlet on the care of the particular animal from a pet store, or write to T.F.H. Publications, Inc., T.F.H. Building, 245 Cornelison Ave., Jersey City, N.J., 07302, for a list of their inexpensive pet care books and booklets. The available publications cover many types of animals.

Developing the Lesson: Proceed to study the fighting behavior of the stickleback with the children. Study the pictures first, and have the class describe the fish.

Have pupils do library research on the stickleback. It is a fresh water fish of the Northern Hemisphere. It is seldom more than 3 inches long. It lacks true scales but has protective plates. In front of the dorsal fin it has spines, the number of which varies with the species. Spines are also found on the ventral fins. These spines are used as defensive weapons. The male constructs the nest from vegetation which it cements to-

gether with a sticky substance secreted from glands located near the kidneys. The male attracts a number of females to the nest. They lay eggs which he then fertilizes. The male guards both the eggs and the newly hatched young.

A similar type of nest preparation and guarding by a more usual male and female parent relationship is exhibited in a short and beautiful color film entitled *A Fish Family* by the Moody Institute of Science. It would complement dramatically the stickleback study and offer points for comparison and contrast.

It might be wise to include the idea that an ethologist is a psychologist of animal behavior. Since many schools today have psychologists, a point of reference in children's experience should be called on where practical.

bottom of a pond by first scooping out a pit in the sand. He carries the sand away a mouthful at a time until the pit is hollow enough. Then he puts weeds on top of the pit and shapes them into a mound. In this mound, he makes an opening which will be the nest itself.

When the nest is finished, the fish, once a dull gray, changes color! His sides become a glowing red, his back a shiny blue-green, and his eyes bright green. It is at this point that his behavior also changes. He protects the nest and drives off any *male* stickleback that comes near.

How far from the nest will the fish fight? Ethologists have observed that the fish has a *territory* that he defends. The nest is the center of the territory, and the stickleback will fight only within a certain area around the nest. He will chase away any strange fish that crosses the unmarked border. The closer the stranger comes to the nest, the more fiercely the stickleback fights. At the nest, he charges furiously at any intruder without any regard for his own safety. The stranger will flee to his own territory, with the stickleback in swift pursuit. Then, as the stickleback swims farther from the nest, he loses some of his fury and charges with less energy. Once they are over the border and in the strange stickleback's territory, the stranger becomes the fighter! He turns on his chaser and drives him back across the border. Back and forth across the border they go, taking turns at being the chaser and the chased.

There seems to be a point, however, where neither one attacks. At this point each fish still extends his spiny sides toward the other in a threatening way, but neither one dares to charge. Instead, they dig frantically at the bottom of the pond, exactly as they did when they were nest building! In this way, they get rid of their fighting spirit. If each stays on his side of the border, the fight is over.

The Search for Key Ideas

Can you find some ideas in these observations that *might* describe not only stickleback fighting behavior, but the fighting behavior of other animals as well? List some of these ideas.

The ethologist studies his observations and tries to draw from them some key ideas about animal fighting. He searches for ideas that he can test on other animals. One such idea is that the closer a stranger comes to the center of an animal's territory, the fiercer the animal becomes.

Is this true of other animals, too? Let us see how a dog behaves when an enemy moves into his territory. How do two male dogs behave when they

meet on the street? They become stiff-legged, their tails go erect, and their hair rises. The closer they come to each other, the slower and more careful their movements become. They pass each other side-to-side, head-to-tail, and then begin to sniff each other's hind regions. The sniffing may go on for quite a while and end in friendly tail wagging. But it may also end with lips curled back to show the fangs, deep growls, hind feet scratching the ground —and finally a fight.

Can you find ways in which the fish and the dog are alike in their fighting behaviors? Is it true that each is fiercer the closer the enemy is to his territory? What is the center of the dog's territory in this case?

The ethologist finds other key ideas in his observations of the stickleback's behavior that he can apply to the behavior of other animals. Compare the list you made with this list made by the ethologist.

1. Male animals set up and defend territories around their homes.
2. The closer a stranger is to the center of the territory, the more fiercely the male defends his territory.
3. The closer it is to mating time, the more fiercely the male defends his territory.
4. The border of a territory can be defined as the place where two males seem to be about equal in fighting spirit.
5. When an animal wants to attack but dares not, he may get rid of his fighting spirit by turning to some other activity.

Using What You Have Learned

1. Review the description of the stickleback's fighting behavior. Find examples of each key idea listed above.

2. If you have a male dog, look for signs that he has a territory. What clues does he give you as to where that territory ends? Compare your findings with those of classmates who have female dogs. Do females stake out a territory?

3. All of the fighting behaviors described so far are connected with *territory*. Do two animals ever fight each other when neither one is in his own territory?

Use the five key ideas on page 305 as a summary of the stickleback's fighting behavior, and also apply these ideas to other animals.

TEACHING SUGGESTIONS
(pp. 305–306)

Background: The answers to *Using What You Have Learned* are:

1. Idea 1: "If a stranger comes close to his nest, he charges with great speed and fury." Idea 2: "The closer the stranger comes to the nest, the more fiercely stickleback fights." Idea 3: "Fighting is related to nest building." Idea 4: "There seems to be a point where neither one attacks." Idea 5: The stickleback mimics nest-building activities.

3. Predators fight for food regardless of territory.

4. This question relates to the stickleback. His fighting spirit increases in *direct proportion* to the proximity of nest-building time and wanes as the young grow older.

5. Instruct children to record what they consider insignificant information. Remind them that what seems insignificant in observing one animal may be important when notes are compared with other investigators.

4. One key idea says, "The closer the stranger to the center of an animal's territory, the more fiercely the animal defends his territory." In the statement, distance from the center is one factor and fighting spirit is the other. The statement shows the relationship between the two factors. A statement of this kind in which one factor is said to increase as the other factor increases describes a *direct proportion*. In science you will find many relationships stated as direct proportions. As one factor gets larger, so does the other. Scientists look for relationships between factors.

Does the fighting spirit of the male change in direct proportion to any factor other than the territory? What is the relationship?

5. How do animals differ in the way they eat? Have half the class observe and take notes on the feeding behavior of a dog, and the other half on that of a cat. Each pupil should write down what the animal does as it approaches the food, how it eats, and what it does as it finishes the food. Compare observations of the dog and cat. How are they alike? How are they different?

Compare observations of different breeds of dogs. Are they alike? Are they different? How? Which are greater, differences between breeds or differences between species?

6. Here are some other behaviors of animals which you might observe: moving about, courting, nest building, taking care of the young, and signaling. ("Signaling" behavior means all the ways in which animals communicate with one another. For example, when a stickleback extends its spines along its sides, it is signaling to an intruder that it is in a fighting mood.) Choose one kind of behavior and observe and take notes on one kind of animal. Compare your observations with the observations of classmates who have studied a different animal's behavior. Search for key ideas. Test the ideas to see if they apply to many animals.

Animal Sense Organs

You have been learning about the search for key ideas that describe animal behavior. These ideas also help to predict behavior. For example, they help to predict when an animal will have the most fighting spirit. Perhaps from your observations you have discovered an idea that helps to predict what will happen when an animal wants to do two things at once—like eat and fight!

You have seen that the stickleback does some very remarkable things, but you still do not know how or why. We have not as yet *explained* behavior. To understand the how's and the why's, we have to examine the animal further.

We know that the stickleback makes a choice between running and fighting. We know that the choice depends on his nearness to the nest. But how does the stickleback recognize when he is near the nest? How does he know when he reaches the border of his territory?

What an animal does depends in part on the information he has about what is going on around him. The sights, the sounds, the smells—all inform him about what is happening. His **sensory** equipment brings him information. To explain animal behavior we must find out about this sensory equipment.

Sensory Receptors

You have sense organs, such as eyes and ears, which bring you certain kinds of information. However, there are some things that you can sense without a special organ. For example, you can sense a change in temperature. This is because your skin is equipped with sensory receptors for heat and cold.

Sensory receptors receive information. Each kind of sensory receptor receives only one kind of information. You do not smell with your ears or feel with your eyes! An animal that does not have sensory receptors for smell has no sense of smell.

Not all animals have sensory receptors. The simplest animals, like the ameba, have only one cell to do many different jobs. However, this one cell is still somewhat sensitive to its surroundings. For example, when the ameba is ready for food, it can tell the difference between a grain of sand and a bit of seaweed. But with such limited sensory equipment, the ameba can take in only a very limited amount of information.

Sensory receptors are made up of **cells.** All living cells can be stimulated. Apply the form of energy to which the cell is sensitive, and there is a reaction in the cell. For example,

TEACHING SUGGESTIONS
(pp. 307–308)

● **LESSON:** How do we become aware of our surroundings?

Background: Collectively, the sense organs are called *receptors*. In simple animals, these "organs" may be merely a collection of similar molecules, usually referred to as *organelles*. In complex animals, the receptors are arrangements of specialized cells.

Usually a receptor causes an animal to become aware of one aspect of its surroundings.

Thermoreceptors receive and transmit changes in temperature.

Chemoreceptors receive chemical stimuli such as smells, tastes, and glandular changes.

Photoreceptors are light-sensitive organs.

In addition there are many receptors that either combine the above or are unique for certain animals. Among these you will find receptors for pain, balance, and muscle tone, and viscera receptors in higher animals.

Learnings to Be Developed: Animals respond to environmental conditions only as they sense the conditions; they sense their environment through different kinds of sensory receptors.

Developing the Lesson: Remind the children that biologically man is an animal (or that he belongs to the animal kingdom). Many of our functions find counterparts in the lower animals. Ask:

Is there anything happening throughout this room which we do not "sense"?

Explain "sense" as different from "know." We "know" radio waves are constantly in the atmosphere, programs and messages by the hundreds, but we have no body receptors to tell us. We know thoughts of children are filling the room, but we have no receptors to "sense" the thoughts of others. Cosmic rays are present, but we have no sense organs to receive them.

Is this building stationary, or is it moving? Do we sense the motion?

The earth spins at approximately 700 miles per hour, at about 40° North, and at the equator at about 1,000 miles per hour. The earth is also going about the sun at a tremendous speed, but we do not feel the motion. We have no receptors for speed. We do have receptors that sense changes in velocity.)

when heat energy from a stove stimulates certain cells in your fingertips, something happens inside the cells. When you eat a hamburger, chemicals in the hamburger stimulate the cells for taste in your mouth. Something happens inside those cells. *In each case, it is in the cell that something happens.*

Scientists group sensory receptors according to the *kind* of stimulation each can receive. Let us study some of these receptors in detail and see what key ideas can be formed about animal senses.

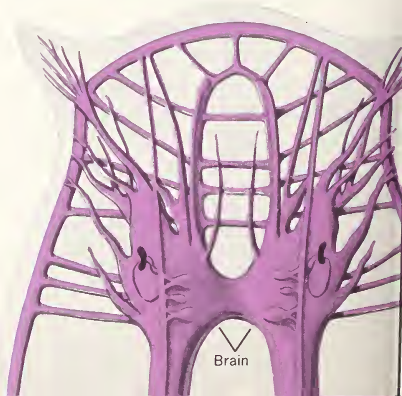
Chemical Receptors

Receptors that are stimulated by chemicals are called **chemoreceptors** (kem-oh-rih-SEP-terz). Some chemoreceptors help us to taste and to smell. Chemoreceptors are very important to animals. They help many animals to survive. Some animals can "smell" danger.

The chemical senses of some animals are much more sensitive than our own. This is especially true of the sense of smell. The fish has a well-developed sense of smell. You remember that the male stickleback chases off other males. However, if a female enters his territory, the male may do a zigzag dance, which is his way of inviting the female stickleback to enter the nest and deposit her eggs.

How can the stickleback tell the difference between a male and a female? A female gives off different chemicals from a male. You know that the water in which cabbage is cooked smells different from the water in which asparagus is cooked. Each vegetable gives off different chemicals. Our sense of smell is sensitive enough to pick up such great differences in smells, but not very small differences. Fish have receptors for smell that are sensitive even to the tiny bits of chemicals given off by another fish as it swims by. These receptors are all over the fish's body.

Even worms are sensitive to chemicals! Planarians (pluh-NAIR-ee-unz) are small flatworms that live in water. They crawl along the bottom of streams. As food dissolves in water, it gives off chemicals. As the worm gets near the food, the food chemicals stimulate receptors on the worm's head. The worm's head moves from side to side.

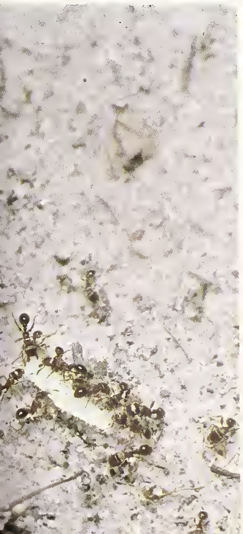


The receptors receive more stimulation as they approach food. The worm moves in the direction of the greater stimulation.

If someone were cooking hamburgers, you might find out where the smell of hamburgers was coming from by sniffing the air. Since more chemicals are in the air near the fire, your sensory receptors pick up this information. Even blindfolded, you could find the hamburgers.

Have you ever watched ants at work? Ants are **social insects.** Thousands of ants live together in a colony, and each kind of ant has a special job to do. There are scout ants, whose job it is to search for food, and worker ants, who must bring the food to the queen and to the young in the nest. The ant's keen sense of smell helps it to carry out its special job. Have you ever watched ants at a spot where sugar has been spilled? First you see only a few stray ants, the scouts, who explore. The scouts report back to the workers, and soon a column of ants, four or five wide, descends on the sugar. To reach the sugar they follow the same path that the scouts used. Each picks up a crystal of sugar and carries it back to the nest to feed the young larvae. On the return trip, the ants keep to the same route that they followed to find

Can you follow the pictures below and on page 310? They show the behavior of ants who have found sugar.



TEACHING SUGGESTIONS
(pp. 308–310)

LESSON: What do the chemical receptors do?

Learnings to Be Developed:

Chemical receptors are one kind of sensory receptor.

They enable animals to adjust to changes in their environment.

Developing the Lesson: Make this an exploration lesson by activity.

Have the children cut up some odoriferous food substance that is usually found in the kitchen (onion, celery, cheese, radish, or cabbage). Ask such questions as:

- *Can you detect the odor even though you do not touch it?*
- *Even with your eyes closed?*
- *How is the odor reaching you?* (Molecules are being carried by air currents.)
- *What part of your body senses it?* (Mouth and nose.)
- *Do you think you have receptors there?*

Inspect your aquarium. Quietly drop non-usual food in a non-usual feeding spot and see if fish notice it shortly.

- *Was the finding of food accidental, due to sight, or to diffusion of chemicals?*

Obtain a few ants or other small insects and place them in a large flat pan. Place sugar, bread crumbs, or other natural foods far from the group and observe.

- *Was the finding of the food accidental or did it appear that they sensed the food's position after a short time?*

Obtain some mixed protozoa or planaria from a pond or stream (or a biological supply house). Project the organisms on a screen using a simple microprojector. Place a few drops of an acid (vinegar will do) in the field of view and observe the reaction of the organisms — avoidance or attraction? Do the same with a base (small piece of drain cleanser). The reactions are in response to the degree of acidity. Try a single crystal of salt.

Discuss: the use of chlorine in drinking water and in swimming pools; citronella candles at picnics and outdoor barbecues; reasons for keeping food out of tents in areas where bears are known to live; reasons for hunters avoiding having the wind at their backs.

Research or review the structure of the human tongue.

the sugar. The workers go back and forth without wandering from the path.

How do scientists explain such behavior? How does the ant keep to the path? Scout ants leave a chemical trail for the workers to follow. As they move across the ground, they squeeze out tiny bits of chemicals from their intestines. The chemicals form a path with a distinct odor picked up by the senses of the workers. The ant does not have a nose, but it does have receptors for smell in its antennae and can sense the odor trail. As the food supply dwindles, the ants leave fewer and fewer bits of chemicals. The odor trail disappears when there is no more food.

Taste is another chemical sense. Insects have receptors for taste that they use in selecting food. These receptors are stimulated only by certain substances and not by others. Did you ever wonder why some insects eat only a certain kind of plant? The silkworm, a moth larva, is attracted to mulberry leaves; the potato beetle, to the potato; the corn borer, to kernels of corn. The chemicals in each of these substances stimulate the insects' taste receptors. Most insects feed on only a few kinds of plants and cannot live on others. Their taste receptors are so specialized that they are not stimulated by certain things that are food for other animals.

Assign library research on the smell receptors in insects. They are located chiefly in the antennae. Some insects have chemical receptors on the legs (butterflies, bees, flies). If a sugar solution touches the tarsal segment of a butterfly, the animal responds by unrolling its proboscis.

Does Light or Smell Enable an Ant to Find Food?

What You Will Need

ant colony	table	sugar
glass jar	metal rail	

How You Can Find Out

1. You can get an ant colony from a biological supply house, or you can dig for one. Be sure that you get the whole colony, including the queen. Be sure also to use sugar ants. The sugar ant is a small, dark-brown insect.
2. To make sure you have the right kind of ants, sprinkle some sugar near the colony and observe the ants before digging.
3. Put the colony in a large, covered glass jar with tiny holes in the cover for air.
4. Make a metal rail around the table, with slippery sides that the ants cannot climb.
5. Remove the cover, turn the jar on its side, and put sugar at the other end of the table.
6. Observe and record what the ants do as they set up a trail.
7. Block off light on one side of the table. Observe and record any changes in the ants' behavior.
8. Rub your finger across the trail in front of the ants as they run toward the sugar.
9. Observe and record any changes in the ants' behavior. Try different-sized breaks in the ants' trail.
10. Record what happens as the sugar supply diminishes.

Questions to Think About

1. Which receptors are the ants using to find the way?
2. Would their chemical receptors work for foods without sugar?
3. How can you figure out from how far away the ant's chemical receptors can sense a substance?

TEACHING SUGGESTIONS
(p. 311)

Background: This experiment and those that follow illustrate the experimental procedure for testing two factors or variables. Before pupils read, ask if they have observed ant trails. In terms of what they have read of sensory mechanisms, what cues might the ants be responding to? Pupils may name cues other than light and smell. List each factor on the board, and all possible combinations. For *light* and *smell,* these would be: *It's light and not odor; It's odor and not light; It's both light and odor; It's neither light nor odor.* Then suggest how each of these possibilities in turn can be tested.

The answers to the Questions to *Think About* are:

1. Receptors in antennae *(antennas* is an acceptable spelling).

2. You would only know if you tried nonsugar foods. Many foods contain sugar or closely allied starches — even vegetables and fruits. So be careful of conclusions. Try drops of vitamins, which do not usually contain sugar.

3. Increase the distance in graduated steps. Recall the importance of accurate measurement.

TEACHING SUGGESTIONS
(pp. 312–315)

LESSON: How do organisms sense light energy?

Learnings to Be Developed:

Radio, heat, light, and cosmic rays are all similar forms of energy radiation.

Differences between them result chiefly from differences in wavelength.

Animals are equipped with receptors for some of these radiations.

Light receptors are called photoreceptors.

In some animals the receptors are complex organs (eyes); in others they are simple cells.

Developing the Lesson: Introduce this section by a discussion of the text and pictures on pages 312–313. Recall that light energy must be absorbed to be effective (recall photosynthesis in a plant). All light receptors have colored pigments to effect this light energy absorption (on the retina of camera eyes; in colored spots on lower animals). Lenses assist in concentrating the light where it can best be absorbed.

Photoreceptors

Another group of special sensory receptors is **photoreceptors.** The Greek word *phos* means light. Can you guess the kind of stimulation to which photoreceptors respond?

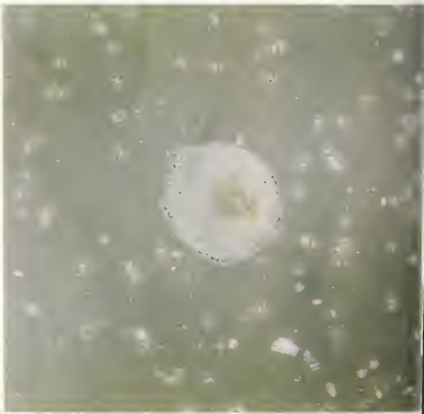
Almost all animals are sensitive to light and will react to differences in brightness. One-celled animals have no special organ that is light-sensitive, but even these animals will move away from a very bright light.

The euglena has a bright red spot, called the *eyespot*, that scientists believe is part of a light-sensitive apparatus. The special eyespot of the euglena is more sensitive and so better able to detect light than the protoplasm of the ameba, which also reacts to light. This specialization is important since, as you may remember, euglenas depend on photosynthesis for their food. It is to their advantage that they expose themselves to the light as much as possible.

The planarian has two eyes, which are sense organs specialized to react to light. Each eye consists of black pigment filled with special cells whose ends continue as nerves that enter the brain. Planarians avoid light and are usually found in dark places, under stones or the leaves of water plants.

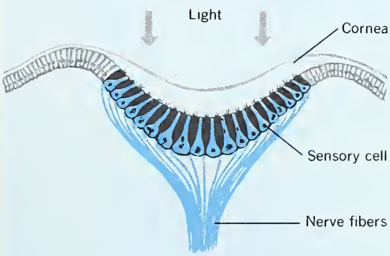
Higher animals have special cells that are sensitive to light. The earthworm has light-sensitive cells at either end; the end regions are most frequently exposed to light.

Although the ameba has nothing that can be compared to our sense organs, it does flow away from bright light and pull itself into a rounded shape, as you can see below. On the left is the ameba before a bright light is shone on it.



If you shine a flashlight on an earthworm, it will disappear into its burrow. A large part of the earthworm's body—not only the ends—is sensitive to light. Find an earthworm and see for yourself.

It took a long time in the history of animals for the eye to develop. The eye is a special kind of photoreceptor. The simplest "eyes" in animals are only colored, cup-shaped tissue. This tissue is made of cells connected to the brain by nerves. As eyes become more complicated, a lens appears that makes it possible for an animal to see some patterns. With additional parts, the eye can form an image. Look at the diagram on page 314 of an image-forming eye. Can you tell what happens as light enters it and stimulates the cells? How is the image formed?



SIMPLE EYE

Pose the following line of questioning after a few picture discussions:

- *Do all parts of our eyes sense light?* (No, only cells of the retina. Remaining parts help transmit light to the retina.
- *Why can a cat see better in semidarkness than you can?* (Human pupils are of circular outline. When the pupils close as far as possible, there remains a small opening through which a great deal of light can still enter. The opening of human pupils is also restricted. Cats, on the other hand, have slit pupils, which act as curtains. Muscular contraction can close the pupil completely or open it to expose the entire retina. This slit pupil is common to most nocturnal feeders. It allows entrance of maximum light in semidarkness and shuts out light almost completely in bright sunlight.)

Darken the room as much as possible for a short time. Instruct pairs of children to observe each other's pupils. The pupils should become fairly large. Pull up all shades and turn on all lights. Have children note the contractions of the pupils. Suggest that they do the same at home before a bathroom mirror.

Proceed to a study of mosaic, or compound, eyes (pp. 314–315). Insects and arthropods such as lobsters and crayfish have compound eyes.

Have available for observation as many pictures of animal eyes as possible. Otherwise use Hammond's *Nature Atlas of America* or a similar animal book. Project the pictures with an opaque projector, and discuss all the different orientations of eyes. For example: Most of the head of the *dragon fly* is occupied by the compound eyes. They see upward, to the front, downward, to the sides, and partially to the rear all at the same time. The eyes of a *praying mantis* change color. At night they are brown. During the day they are pale green. Suggest possible uses for such adaptations. The *horse* has the largest eye of any terrestrial vertebrate. Its lens is larger and admits more light at night. Its sensitive retina receives a larger image on more receptor cells. This allows for finer detail in image formation. The eyes of *land snails* are on the tips of two tentacles. When it is touched, the snail withdraws the eye like a sock turning inside out. The eyes of the *turtle* are protected by three eyelids. (We have two, upper and lower.) The third eyelid is a somewhat transparent membrane, pre-

Animals with backbones (vertebrates) have image-forming eyes. Sometimes such eyes are called camera eyes. Can you explain why?

All camera eyes have the same kinds of parts and work according to the same principles. However, they are not exactly the same in all animals. There are differences that are related to the animal's way of living. Some animals have more rods in the retina than other animals. Rods are especially sensitive to light and can be stimulated even by very little light. Such animals often have a slit pupil instead of a round one. The slit pupil can open wider and thus allow more light to enter the eye. The way the eye is made is related to how it works. With such an eye, an animal can hunt when there is very little light. Can you name some animals that hunt at night?

Other differences make it possible for the eye of an animal to adjust to size, shape, pattern, color, and distance. Birds, such as swallows, that feed in flight have *two* areas at the back of the retina where vision is sharpest; other animals with camera eyes have only one such area. These two areas can register a great deal of information from a very wide angle. A swallow can see and capture in flight a juicy insect way off to the side of the eye. What other animals have good side vision?

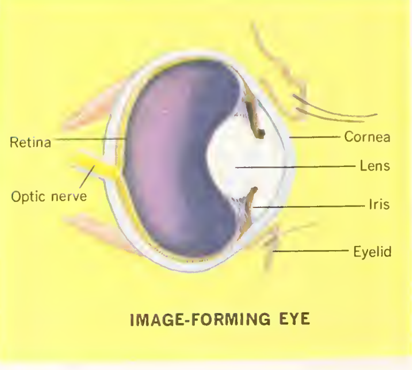
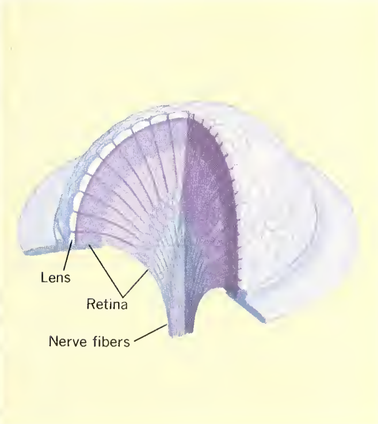


IMAGE-FORMING EYE

What is the shape of the pupils of the cat's eyes? How does this shape help the cat see when there is little light?



MOSAIC EYE
The insect has a mosaic eye made up of many small units, each unit with a small bundle of light-sensitive cells and a lens. The mosaic eye does not give as sharp an image as the "camera" eye of man gives. However, some insects' eyes probably form very good images—these insects have been seen trying to get nectar from the flowers on wallpaper.

Insects have **mosaic** (moh-ZAY-ik) eyes. These are made up of separate **facets** (FASS-its), or small surfaces, like those you see on a diamond. Beneath each facet are light-sensitive cells. These facets serve as lenses to gather light. Because each facet is separate from the others, the light-sensitive cells of each one can be stimulated separately. Since light has a wave motion, waves go out in all directions from any light source. However, mosaic eyes do not pick up all the wave motions. As light enters each facet, only some of its waves pass through. Each facet in the mosaic, then, registers a different pattern of light and dark.

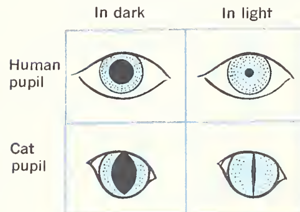
Insects make use of these patterns to find their way. Their eyes do not register a clear image of an object, as man's eyes do, but insects are very sensitive to the movements of objects around them. Any movement changes the amount of light falling on one of the facets, and so the slightest motion of enemy or prey is quickly detected.

sumed to be a protection underwater. The tuatara (too-a-*tar*-a), an almost extinct reptile of New Zealand, has two catlike eyes plus an additional third eye on the top of its head. The third eye is not functional but has the remains of a retina and other eye structures.

ADDITIONAL ACTIVITIES:

Arrange for the school nurse to explain how the human eye functions, how eye tests are given, and how to care for the eyes.

Recall the pinhole camera described on page 201 as an analogy to the human eye.



TEACHING SUGGESTIONS (p. 316)

Background: Suggested home assignment: Place a string of colored lights outside in the spring. Observe for 15 minutes or so and attempt to see if any particular color attracts more insects than others. Investigate the so-called insect-repellant electric bulbs.

An alternate classroom activity might be done using a large jar with some trapped flying insects such as moths, ladybird beetles, or flies. Conduct the experiment in a darkened closet or deeply shaded spot in school. Backstage in the auditorium would be an excellent place. Use a common flashlight. Cover it with cellophane of different colors for about 1 or 2 minutes at a time. Does one color attract the insects more than another?

The answers to the *Questions to Think About* are:

1. Depending on numbers, discuss the validity of any conclusions. Discuss significant differences based on large numbers versus small numbers.

2. They can discern the natural colors of foods. They can see predators better.

EXPERIMENT

Can Some Insects See Differences in Color?

What You Will Need

sugar solutions   vegetable dyes of different colors   boards

How You Can Find Out

1. Make some sticky sugar solutions of different colors using the vegetable dyes.
2. Paint the solutions on the boards, using a different board for each color.
3. Prop the boards against a tree trunk and leave for 24 hours.
4. Collect the boards in the morning and count the insects trapped on each solution. Record.
5. Repeat for several days, recording each morning.

Questions to Think About

1. Based on your records, can you write a concluding statement about whether or not some insects can see differences in color?
2. How does being able to see colors help an insect survive?

Thermoreceptors

Another group of receptors is called **thermoreceptors.** The Greek word *thermos* means heat. Thermoreceptors are sensitive to changes in temperature. Being able to detect temperature is important to an animal. An animal will die if the temperature is too high or too low. There are cold-blooded animals, such as snakes, whose body temperatures change with the changes in the outside temperature. But even they can survive temperatures only within a certain range.

An animal must be sensitive to temperature change. Its body carries on its work best in the temperature suited to it. The polar bear thrives in temperatures too low for the elephant. The thick fur of the bear is an excel-

lent insulator. Fur can also insulate against heat, but not always enough. Fur seals, for example, cannot stand warm weather. If the temperature of the water in which they live goes much above 50° F., they will die of overheating.

All animals can get used to some temperature changes; they become **acclimatized** (uh-KLY-muh-tyzd). That is, they adjust to different climates. They can only do this, however, within certain limits. These limits are set when they are born.

Animals seek out places around themselves where the temperature is most favorable to them. Watch how your dog will move about on a hot day, seeking a cool spot. Or perhaps you have noticed how grasshoppers seek out a hot, sunny place in which to bask. The animal in each case does not think, "I'm too hot," or "I'm too cold; I'd better move." But activity within the cells of its body changes with the temperature.

If an animal is too hot, its body acts to get rid of heat. Evaporation is one way to cool off the body. Animals that sweat or pant lose water by evaporation, and their bodies are cooled. In the opossum and some rats, saliva flows freely on a hot day. These animals lick their fur. The water evaporates and cooling results.

Changes in blood vessels also help to get rid of heat. Blood vessels near the skin get larger when the temperature goes up. More blood flows into them. The more blood near the surface of the skin, the more heat that can be given off from the body into the air. Will hot soup cool more quickly in a cup or in an open dish?

There are more ways in which animals can adjust to cold. Some animals hibernate. In hibernation the animal's body usually remains at about the same temperature as the outside air. As its body temperature goes down, its heart also slows down, and less oxygen is taken in. Some animals, like the hamster, will wake up when the air temperature drops dangerously low. But if its temperature receptors are not working properly, the animal will die in freezing temperatures.

How does licking its fur keep the opossum cool on a very hot day?

TEACHING SUGGESTIONS
(pp. 316–318)

LESSON: How do animals sense changes in temperature?

Background: The biting reaction of mosquitoes appears to be dependent on temperature rather than on a sense of smell.

Leeches that suck the blood of humans have temperature receptors; leeches that prey on cold-blooded animals do not seem to have any.

Ants move their larvae and pupae from one part of the nest to another when the temperature changes during the day or season. One researcher found that ants can detect a difference of only $\frac{1}{4}$° C.

Learnings to Be Developed:

Specialized organs can detect changes in heat intensity.

The entire organism reacts to the changes in temperature.

Developing the Lesson: Introduce the human receptors of heat by a demonstration-experiment: Have a pupil place one hand in a bowl of cold water and the other in a pan of hot (not dangerously hot) water. After each hand has become accustomed to the surrounding temperature, have the pupil place both hands in a pan

of water that has an intermediate temperature. The hand from the cold water will interpret intermediate temperature as hot, while the other hand will feel the same water as cold.

Have at least two children go through the above sequence and then have them relate their experiences to the class.

This should raise the question of *why?* Discuss all possible explanations. The best explanations should lead to the idea that our receptors in many cases "adapt" to constant irritation by getting tired and ceasing to report. There are separate receptors in man for high temperatures and low.

Background: Warm-blooded animals (mammals and birds) attempt to maintain a constant body temperature.

Cold-blooded animals tend to live within a greater range of body temperatures. Their body temperatures changes with changes in the environment, usually maintaining a body temperature only a few degrees above the outside temperature.

Animals that hibernate usually have lower body temperature while in an inactive state.

There are still other adjustments that an animal makes to low temperatures. It may shiver, as we do. This movement produces more heat in the body and saves what heat it has. Blood vessels in the skin become smaller, so less blood is near the cold air. Hairs or feathers may stand up on end. An animal may cross its legs or shrink up so there is less skin exposed to the cold air.

Bees have a very special way of keeping the temperature in the hive from dropping too low in winter. Tens of thousands of bees may cluster together in a hive. When those on the outside of the cluster get cold, they flap their wings and move their feet. Their movements make bees in the next layer active. The activity spreads until all the bees are flapping their wings and moving their feet. What happens to the body temperatures of the bees as they move about? What happens to the temperature of the air inside the hive?

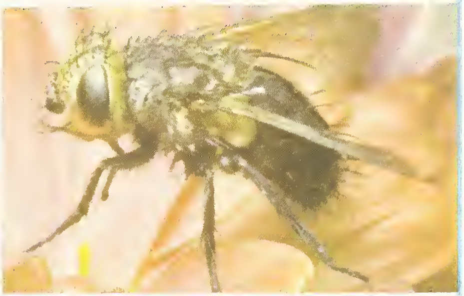
Next fall, record what various animals in your community do to prepare for the cold weather.

A little brown bat hibernates when the temperature goes down. How does this help the bat to survive during the winter months?

How are these bees raising their body temperatures? What happens as their body temperatures rise?

Mechanical Receptors

Still another kind of receptor receives stimulation from touch, pressure, and sound. These **mechanical receptors** are sensitive to forces pushing against them. They serve as receptors of physical changes in the surroundings. Some insects have small bristles on the surfaces of their bodies. There are receptors where the bristles are joined to the surface that can pick up information about what the insect is crawling over. The bark of one tree would push against the bristles in a very different way from the bark of another tree. As this information reaches the nervous system, changes may occur in the animal.



EXPERIMENT

Do Ladybugs Prefer Rough or Smooth Surfaces?

What You Will Need

ladybugs   tree bark   smooth board

How You Can Find Out

1. Set up a runway with the tree bark at one end and the smooth board at the other.
2. Start the ladybugs on the rough surface. Observe and record what happens when the ladybugs reach the smooth surface.

Questions to Think About

1. Which surface do ladybugs prefer?
2. How would you explain the preference?
3. Does this behavior help the ladybugs to survive?
4. How can you find out which receptors the ladybugs use?

Your pupils' answers to the posed questions may be inconclusive. Remind the pupils that scientists insist on large numbers of trials before accepting as valid even temporary conclusions.

TEACHING SUGGESTIONS
(p. 319)

LESSON: Do animals have a sense of touch?

Learnings to Be Developed: Mechanical receptors record touch sensations.

Developing the Lesson: Briefly illustrate man's touch receptors by having pupils blindfold each other. Then have them feel substances of different textures, such as pieces of cotton, velvet, wood, etc., of uniform size. Have them place their hands, palms down, lightly on each substance and later have them identify the objects by their feel.

- *Where do you receive the most distinguishable touch sensation?*

The palms have very few receptors in comparison with the fingertips. Also, the palms usually are more thick skinned. Try to elicit these ideas from the pupils.

Try the experiment using substances other than tree bark and smooth board, e.g., cellulose sponge and glass jar, etc.

If the ladybugs seem to prefer rough surfaces, point out in answer to question 3 that a ladybug in a crack in tree bark is less accessible to birds and other predators than one on a smooth surface.

TEACHING SUGGESTIONS
(pp 320–321)

Background: How *do* bees find their way from the hive to the nectar? A bee's eye, like that of a fly, is multifaceted. Each facet consists of a transparent lens, behind which is a central cone surrounded by eight light-sensitive cones. Light entering each lens passes from the central cone to each of the eight light-sensitive cones. In the process, the entering light is *polarized* a certain amount, depending on the angle at which sunlight enters the lens originally, so that each of the eight light-sensitive cones receives a different amount of light.

Sunlight itself is unpolarized. That is, each photon of light consists of electric and magnetic fields of force that rise and collapse at right angles to each other and at right angles to the direction in which the photon is traveling. For any stream of photons, the rising and falling fields of force can be in any random set of positions, just as the guide vanes of a rocket can be at any angle relative to the direction of flight as long as they remain fixed at right angles with reference to the rocket itself. It is the randomness of these fields of force that is meant as unpolarized.

Perhaps the most important feature of animals is the many ways they are able to change as their environment changes. In studying each animal as a whole, we find that these changes are rarely simple reactions.

All the adjustments we have talked about are not planned by the animal.

PATHFINDERS IN SCIENCE

Karl von Frisch

(1886–   ) Austria

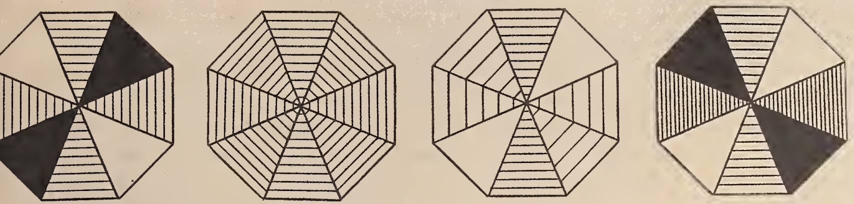
One day in 1923, Karl von Frisch, a zoologist at the University of Munich, Germany, laid a sheet of white paper on a table he had set up in a field. He placed some honey on the sheet of paper and waited for a bee to come. He was studying the habits of bees, and this was his way of attracting them.

Sometimes he waited several days for a bee to appear. But he noticed that soon after the first bee had discovered the honey and flown away again, other bees came—sometimes hundreds at a time.

This puzzled von Frisch. He wondered whether the first bee had led the other bees to the honey. If so, how did the first bee tell the others what it had found? To find out, he decided to conduct a series of experiments. He built a hive with glass walls and attracted a swarm of bees to it. Then he marked several of the bees with spots of color so that he could easily follow their furious movements.

In this way, von Frisch discovered that the bees did a dance in order to tell each other where they had found nectar. If the first bee discovered a rich supply of nectar close to the hive, it would return to the hive and begin to dance in circles. If the nectar was far from the hive, the

The queen bee does not send a message out saying, "Flap your wings: it's getting cold." Somewhere in an animal's nervous system, information from sensory receptors is pieced together, and the proper adjustment is made. In the rest of this unit you will find out what happens in the nervous system.



NORTH EAST SOUTH WEST

Bees use the pattern of polarized light from the sky to find the sun's position. Von Frisch found that if he artificially disturbed the pattern, the bees' dances changed. Above are four patterns made by von Frisch. If he used a pattern he could not identify in the sky, the bees danced with no particular direction. Find out more about these patterns. *

first bee would do another kind of dance. It would wiggle its body from side to side while facing in one direction. The wiggles told the other bees how far away the food was and the direction in which the first bee faced told them in what direction to fly.

The other bees would gather around the dancing bee and soon they would fly from the hive to search for the nectar the first bee had found.

If the bees swarmed from their old hive, scouts would search ahead for suitable new hives. The scouts would report back by dancing in special ways. The dances told the other bees what the scouts had found. Soon the entire swarm would set off for their new hive.

During his experiments, Karl von Frisch did nothing more exciting than watch his bees closely and note carefully how they behaved. He made records of all that he saw. His experiments were as exciting to him and to other scientists as a football or baseball game is to others.

Von Frisch's experiments with bees have led to an increase in our understanding of communication among insects.

It might be interesting to the pupils if you were to make such an eight-sided Polaroid filter and have them note how the pattern changes as they face in different directions. The Edmund Scientific Co., Barrington, New Jersey, 08007, sells sheets of Polaroid material that can be used for this purpose. Suitable books that describe von Frisch's experiments include The Dancing Bees, by Karl von Frisch (Harcourt 1961), and Animal Navigation, by J. D. Carthy (Scribner, 1956).

When sunlight enters the earth's atmosphere, however, the sunlight is *plane-polarized*. That is, the atmosphere has the ability to suppress those photons in which the electromagnetic fields are at certain angles to it. When sunlight is looked at through a Polaroid filter from the surface of the earth, and the filter is rotated, the filter will block out the sunlight when the filter is in a certain position. This position is at right angles to the plane of polarization.

A bee's eyes work similarly to a Polaroid filter. In each facet, the eight light-sensitive cells act like a piece of Polaroid material that has been cut apart and fitted together again to form an eight-sided polygon. For any given position of the sun, the pattern of polarization will differ if the Polaroid filter is pointed in different positions relative to the sun. The four diagrams on page 321 show four possible patterns. Von Frisch obtained them by making just such an eight-sided Polaroid filter and pointing it toward different parts of the sky. Apparently, a bee can tell the direction in which it is flying by the particular pattern of light and dark made within its eye by the plane-polarizing effect of the atmosphere upon sunlight.

TEACHING SUGGESTIONS
(p. 322)

Background: The answers to *Using What You Have Learned* are:

1. a. Cat and owl eyes allow these animals to perceive food in the dark; temperature receptors cause the body to compensate for changes in temperature; taste and smell receptors lead animals to food.

b. Geologic history gives evidence that organs such as the eye of man arose only after millions of years.

c. The lens of the mammal's eye focuses the available light to form an image. The pupil allows for control of illumination intensity. Sound receptors also are adapted for the environment. In air the ear collects vibrations and funnels them into the receptor. Water animals, because the water is much more dense than air, have receptors that are flat on the surface.

d. A variety of taste receptors were mentioned in the text. The function was the same in each case, but each was adapted to individual needs.

2. The design here should be such that the mentioned items are eliminated as causes of reaction. A sound that is loud but does not produce visible vibration must be provided; a hidden bell or buzzer is satisfactory.

Using What You Have Learned

1. Do you now have a list of key ideas about animal senses? Check your list against the following list, and find examples of each of these key ideas:

a. The sensory equipment of an animal helps it to survive.

b. Complicated sensory equipment took millions of years to develop.

c. The structure of sensory receptors is related to what they do.

d. There is both variety and similarity in the ways in which animals take in information from their environments.

2. Can a goldfish hear? Write a plan for an experiment to find out. How can you be sure that it is what the fish hears that changes its behavior and not what it sees, feels, or smells?

3. Insects have mosaic eyes made up of separate facets. Not all light waves pass through. A polaroid filter will also keep out some light waves. A polaroid filter has tiny crystals that let only certain light waves through.

Use polaroid sunglasses or a polaroid filter to examine the shiny side of aluminum foil in bright sunlight. Turn the polaroid filter around slowly while you examine the foil. What change do you notice in brightness?

Look at the sky on a cloudy day and on a sunny day. Turn the polaroid filter as you look. How does the polaroid filter change the light? Write about the changes that you have seen.

4. One good way to observe insect behavior is to make a simple cage in which insects may be kept. You will need a lamp chimney screened at the top and pressed into the soil of a flowerpot containing a growing plant. You will also need a dish in which to keep the flowerpot. Some string or a rubber band will hold the screening tightly to the lamp chimney. What will serve as insect food?

The food supply should include [illegible] the insect.

Explaining Behavior

You have learned how an animal senses what is happening around it. You have seen that sensory receptors can be stimulated in various ways. However, this does not *explain* an animal's behavior. It only tells us how an animal gets information.

To explain behavior, we must study the nervous system. The nervous system controls behavior. When the school bell rings, your sensory cells for sound are stimulated. The stimulation is passed along sensory nerves to the brain. But your brain does not send out a message to the motor nerves to get up and go. The meaning of the bell is checked against other meanings stored in the cells of your brain. You search for more information. You automatically glance up at the clock to see if it is the right time for dismissal. You look at the teacher to see if she has heard. You look at your work to see if it is ready to hand in. All of these bits and pieces of information are fed into the brain by the sensory nerves before a message goes out to your motor nerves.

Can you explain the behavior of children playing in the schoolyard when the school bell rings for the start of classes?

TEACHING SUGGESTIONS
(pp. 323–326)

LESSON: What is the nervous system?

Background: The *structure* of an organism to a large degree determines its behavior. It determines the pattern of response. Reflexes are ready-made pathways—part of the biological architecture.

Rudimentary behavior in the human is controlled by simple reflexes. Coughing, sneezing, salivation and tearing are examples of reflexes. In simpler animals similar reflexes exist.

There are also more complex series or chains of reflexes which are instinctive, such as the motion of the head, lips, arms, hands, and tongue when an infant's cheek is touched. Such a stimulus touches off the series of actions that end in sucking the touching finger. This total activity, which is inborn, is usually called *instinct*. Actions such as those of courtship and nest building by birds, web building by spiders, and hibernation in some mammals, are all examples of instinct.

Learnings to Be Developed: The nervous systems of animals control their behavior.

A nervous system consists of all the receptors and effectors that respond to stimuli plus a control center.

As we study both simple and complex organisms, we see how the complexity of nervous systems increases with the complexity of the organism.

A study of nerve structure is necessary for an understanding of animal behavior.

In studying animal behavior we find a similarity to some of our own actions.

Developing the Lesson: Introduce the lesson by a few demonstrations of simple reflexes in the children.

Recall the pupil reflex on page 313. Ask:

• *Did you learn this response?*

Give each child a small sharp-tasting piece of candy. Small "sour lemon" drops are ideal. Have them hold the pieces about an inch from their mouths for about a minute. Ask:

• *What sensation do you feel that you did not feel before?* (The salivation process should have begun.)

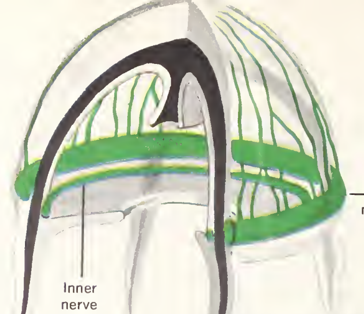
How the Nervous System Developed

Not all animals have a nervous system. You know that in the course of the earth's history, living things have changed. The first animals did not have nervous systems. They were simple animals with one cell to carry on all the work an animal needs to do to stay alive.

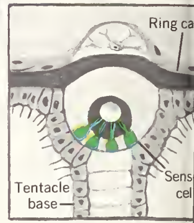
Very slowly, changes appeared. Animals became more complex. Many-celled animals came into existence, with many parts to their bodies. For these animals to survive, the many parts of the body had to work together. The nervous system has the job of **coordinating** the parts of the body.

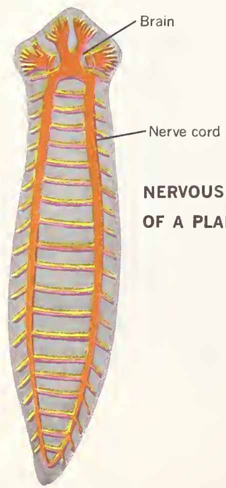
Over a billion years ago, animals like the jellyfish appeared. This animal has a very simple kind of nervous system. The jellyfish has a few sensory receptors and a nerve net through which messages go back and forth. Look at the picture to see the nerve net of the jellyfish.

Gradually nervous systems became more complicated. In animals like the flatworm, nerve cells are clustered in a tiny mass between the eyes. This is a kind of "early" brain. Nerves branch out in all directions from this brain, bringing in information from the senses and carrying messages out. In this way, the various parts of the animal work together.



NERVOUS SYSTEM OF A JELLYFISH





NERVOUS SYSTEM OF A PLANARIAN

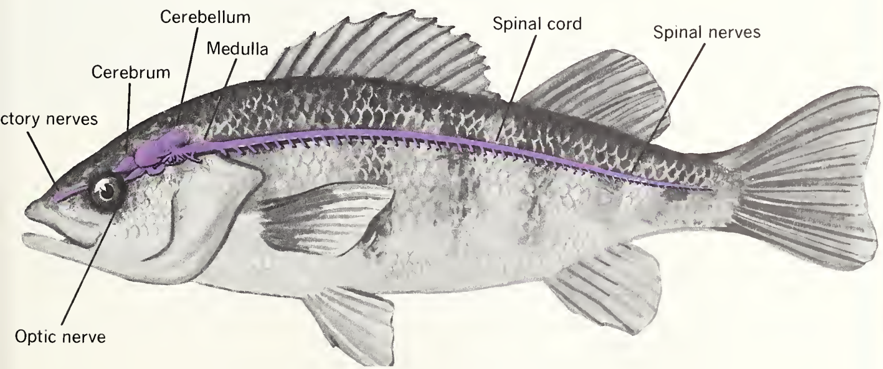
The Nervous System and Behavior

The fish has a **central nervous system** like the one in the picture. A central nervous system consists of a brain and a spinal cord. You remember that ethologists have found out many things about the behavior of the stickleback fish. What happens in the nervous system that causes its behavior? Let us look at the food-getting behavior. By experimenting, scientists have discovered that the stickleback (1) searches for food with more or less energy depending on how empty its stomach is, the kind of food nearby, and the temperature of the water; (2) eats fast at first and then slows down; (3) eats enough to keep its stomach full up to a certain limit; (4) may turn to food when there is a conflict between two other kinds of behavior—perhaps fighting and escape.

Before the stickleback searches for food, the fish must have information about how cold the water is, what kind of food is nearby, and how full its stomach is. Only then can the brain send out the proper message to other parts of the body. There must be a central system where information is brought in about what is going on around and inside the stickleback.

Scientists think that there are centers in the nervous system to handle various jobs. One such center might control appetite. In their natural surroundings, fish do not die from overeating. Some food goes by, and the

NERVOUS SYSTEM OF A FISH



Did you learn to salivate?

Recall some examples of simple reactions from the previous section on animal sense organs.

Proceed to discuss text and picture on page 323. Then go on to examples of the development of nervous systems.

You might want to introduce other examples of system development, such as:

Hydras have nerve cells arranged in an interconnected network but without a control center. The hydra belongs to the same phylum as the jellyfish (p. 324).

The *planarian* is a flatworm. It has a double nerve cord running the length of its body, with an interconnecting ladderlike arrangement between the cords. In the head we find a rudimentary brain, which consists of a mass of nerve tissue. Tapeworms, liver flukes, and blood flukes belong to the same phylum as flatworms. Many studies are being made today on this organism, since it appears to be at the beginning of the learning ladder. Perhaps it can "learn." Much of the body space of the planarian is taken up by a branching digestive system. The *eyespots* of planaria can detect direction and intensity of light but cannot form images. The bulbs or flaps, that look like ears can detect food

at a distance by a sense of smell.

The *earthworm* has a still more developed nervous system. A system of small nerve masses (ganglia) are found along the length of the body. A very brainlike structure is found near the head region.

In vertebrates a central system of nerves connects with a peripheral system. This central system coordinates activities by means of the brain.

ADDITIONAL ACTIVITIES:

Divide the class into committees to do library research on the nervous systems of the vertebrates. Each committee should report on brain shape and size in relation to body size and on special nerve receptors, if any, that help the animal survive. Specific animals may be assigned to each committee: horse, shark, man, rabbit, frog, alligator, etc.

Follow the previous activity by making a chart of comparative brains, using either pictures or the children's own diagrams. Plaster or clay models of the brains could be constructed also.

Perhaps a local meat store could put aside the brain of a cow, sheep, hog, or other animal for your class to study.

message is taken in by the fish. The message goes to a center where appetite is controlled, and the message is checked against information there. If the information is that the stomach is full enough, this information is fed back into the food-seeking center, and the fish ignores the food.

But ethologists know that the temperature of the water affects how much the stickleback eats. The fish eats less when the temperature is low. (In general, the work of cells is speeded up by heat and slowed down by cold.) The appetite-control center must also get the information about how cold the water is. The center must balance information about both stomach fullness and temperature. Only then can it send out the correct message—to eat or not to eat.

Why, then, may the stickleback begin eating during a fight? Scientists think that the center that controls food-getting must be very close to the center that controls fighting. The fish uses its mouth for both fighting and eating. Therefore, information that something is in the mouth is carried to *either* the food-seeking center *or* the fighting center. If that "something" in the mouth is an enemy, the message ought to go to the fighting center, so the fish will continue to fight. But if the centers are very close together, the message may end up in the food-seeking center. Then the stickleback, in the middle of the fight, begins to search for food!

Centers for temperature and appetite control in mammals are located in a part of the brain called the **hypothalamus** (hy-poh-THAL-uh-muss). Nerves carry messages from the senses to the hypothalamus. Cells in the hypothalamus are stimulated and release chemicals. The chemicals act as messengers to put other systems into action.

Scientists go underwater to study the behavior of certain fishes.

Today some of the most exciting work in science is being done on these chemical messengers. When more is known, perhaps behavior can be explained in terms of what happens within the cell.

Using What You Have Learned

Use what you now know about how animals behave to do the following experiments.

EXPERIMENT

Does Temperature Affect the Appetite of a Goldfish?

What You Will Need

a goldfish	fish food	ice cubes
bowl	water	

How You Can Find Out

1. Fill the bowl three-quarters full of water, and let it stand overnight. This will remove the chlorine.
2. Measure the temperature of the water. Record the date and the temperature.
3. Place the goldfish in the bowl.
4. The directions on the package of fish food will tell you how much to use. Feed less than the amount suggested so that the fish will eat it all. Measure the same amount of food each day for one school week. Skim off any uneaten food after an hour, dry it, and measure it. Feed at the same time each day.
5. Keep a record of the water's temperature and how much food the fish eats.
6. The next school week, lower the temperature of the water one hour before feeding time. Take out some water and add ice cubes until the water temperature is 20° F. lower than it was before. Repeat #4 above.*

Questions to Think About

1. Does the appetite of the fish change when the water is cooler?
2. Are living things more active when it is cold or when it is warm?

In step 6 be sure that any heater is removed. Ice should be added daily to keep the temperature as uniform as possible.

TEACHING SUGGESTIONS
(p. 327)

Background: If you maintain an aquarium in the room, the preliminary step #1 is not needed. It would be best to begin this experiment after cleaning the aquarium, since food residues might otherwise be heavy.

After reading steps 1 to 6, ask (if your regular setup is to be used):

- *Can we use our class aquarium?*
- *What must be done before using it for the experiment? Why?* (As many variables as possible must be removed since we are studying the relation of food intake to temperature. Therefore, food residues must be removed.)

In step #4 ask for criticism of the food-measuring technique.

- *Can we be sure we collected all uneaten food?* (No. Some will be dispersed by the activity of the feeding fish, and some will fall to the bottom.)

The answers to the *Questions to Think About* are:

1. Probably, if we accept eating as an indication of appetite. In general, cold-blooded animals have reduced rates of activity at lower temperatures, and their energy needs diminish in proportion to the temperature drop.

2. Based on the evidence collected, no answer is possible here. In fish, less activity, metabolic and physical, takes place. In other species and phyla, more activity could result, as in bees and ants.

TEACHING SUGGESTIONS
(p. 328)

Background: Here you have an exploration which may not yield nice clear-cut results. In other words, the results may only hint at a possible conclusion. This is the nature of scientific investigation. The hint is followed up by many similar experiments in which the conditions are varied gradually. Point this out regardless of how clear-cut your own particular results may be.

Consider conditions in the experiment that could be too extreme to give results: The lamp could cause a rise in temperature too high to support mitosis, or any cell life at all. It might simply slow up the process of cell division. If not too severe, it might increase the rate of growth over the rate at room temperature. In general, rise in temperature causes an increase in speed of cell division and growth. There are upper limits, however.

EXPERIMENT

Does Temperature Affect How Fast Animals Develop?

What You Will Need

containers of pond water	electric light	frog or toad eggs
elodea	thermometer	boxes

How You Can Find Out

1. Look for eggs in ponds or swamps in late winter or early spring. Some frogs lay eggs that float on water in a mass of clear jelly. Bring in one of the egg masses in a bucket of pond water.
2. Divide the mass into three batches. Put the batches in containers of pond water—having elodea plants—in three places where the temperatures are different. One batch might be inside a box. The electric light will keep the temperature of the box higher than room temperature. Record the temperature of the box every day at the same time.
3. Make a second box, but put no light in it. Put a second container of eggs inside. Chill it twice a day by adding ice cubes of frozen pond water, first removing some of the warmed water.
4. Keep the third set of eggs at room temperature. Record the temperature.
5. Examine each egg mass every day with a magnifying glass. Write down a description of what you see in each mass.
6. On which day do you first see tadpoles appear as the eggs hatch in each box?

Questions to Think About

1. How does temperature affect the speed of hatching?
2. Do you think seasonal changes affect the development of animals? How can you find out?

Is Animal Behavior Inherited or Learned?

You have seen that there is a great variety of animal behaviors. You have seen that these behaviors are made possible by the structure of the animal—its sensory equipment and its nervous system. But how can we explain the fact that a robin builds a nest that is different from a cardinal's nest? Do robins watch other robins and learn from them? Are they born knowing how to build a nest in a certain way? Did the stickleback learn, or was it born with, its way of defending itself?

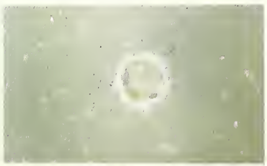
Early Ancestors of Animals

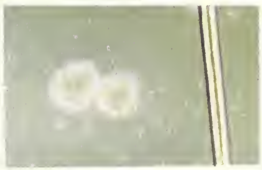
To find part of the answer to our question, we must go back into the history of animal life on earth. If we could go back a few billion years, scientists think that we would find only one-celled animals. These animals lived in the sea. After millions of years, more complicated animals appeared. They were offspring of the single-celled animals.

A one-celled animal reproduces by dividing in two. But the split is not necessarily an exact one, and the two new animals are usually not identical. At some point in the earth's history, an offspring appeared that was very different; it had more than one cell. Perhaps this difference was the result of changes in the chemicals in the sea. No one knows for sure. When this animal reproduced, it passed on the differences to its offspring, who in turn had offspring with more than one cell. An entirely new group of animals gradually came into being.

You know that offspring from the same set of parents are not identical, unless they are identical twins. You are different from your brothers and

Two animals from one. The ameba reproduces by splitting in two.





TEACHING SUGGESTIONS
(pp. 329–331)

LESSON: Is animal behavior inherited or learned?

Background: We deal in this section with some aspects of the development and evolution of life. Your pupils may raise some questions allied to our topic and it would be wise to be prepared. Questions such as "Did man come from the apes?" and, "How do we know about life thousands and millions of years before recorded history?" could arise.

In regard to the first: No modern anthropologist believes that man descended from any form of life existing today. They theorize that man *probably* evolved 20,000,000 years ago from an ancestor similar to the ancestor of today's apes and monkeys. It is generally believed that hominids (including man) and pongids (including the anthropoid apes) had a common ancestor.

Bits of knowledge regarding rock formations and fossils have been acquired over the last two hundred years and pieced together to form a fairly reliable sequence of what occurred during prehistory.

Fossils have included intact parts of bones and teeth, small animal bodies trapped in tar or amber,

shells of marine animals, casts of animals, tracks, and plants, and petrified remains of entire organisms.

The history of the development of life is necessary for an understanding of the development of behavior and learning. Our human abilities are possible only in an organism with a complex nervous development.

Learnings to Be Developed:

Nervous systems in animals have developed over millions of years.

Although all human beings have common ancestors, individuals are quite different from each other.

All human beings have common characteristics.

These characteristics are found in people who are not close members of our families.

Developing the Lesson: Ask:

- *How large is your family?*

The answers will vary, but each child will probably limit his total to the nuclear family: mother, father, and siblings. After a few numbers have been given, introduce the idea of the extended family.

At this point inject the idea that to study a family, we should know as much about as many members as possible.

sisters. Puppies in the same litter are different. So are kittens. Some of the differences are passed on to offspring. The offspring then have these new characteristics.

The differences may be very slight from one generation to the next. If one puppy has thicker fur than its parents, then perhaps some of its puppies will also have thicker fur. Changes go on generation after generation. They have been going on for millions of years. They explain why we have a tremendous variety of living things on earth today.

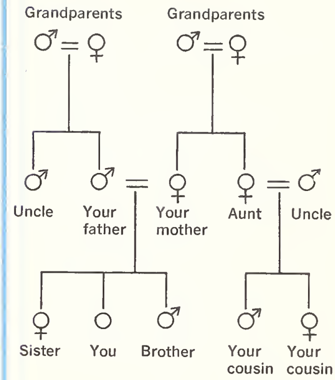
The story of how dogs and cats developed shows us how the process works. If we could go back in history about 50 million years, we would find that there were no dogs and cats. There *was* a family of animals called **Miacidae** (my-uh-SIH-dee), which were about the size of house cats. The miacids were hunters and had claws and teeth suited to a diet of fresh meat. Like those of all animals, the offspring of a pair of miacid parents differed slightly. One of the offspring was larger and stronger than its miacid parents. It also had longer legs. The longer legs enabled the animal to run faster and hunt better. The larger size and greater strength made it easier for the animal to hunt larger prey. This animal, because it was such a good hunter, was able to live a long time and have many offspring. Its offspring had larger and stronger bodies and longer legs than its miacid ancestors. The offspring stood a better chance of surviving and of having babies than did the ancestor miacids. Today the descendants of these animals form the family of **Canidae** (KAN-uh-dee). Wolves, foxes, coyotes, and dogs are some of the animals in the canidae family.

At some point in history, one of the miacids gave birth to an offspring that was different in another way. This offspring had very sharp claws. Its teeth were different from its parents'. It could hunt and eat prey that an ordinary miacid could not manage. This animal could climb trees to lie in wait for prey, pounce on it, and hold it tightly in its sharp claws. Offspring of this animal formed the family called **Felidae** (FEE-luh-dee). Lions, leopards, wildcats, and house cats are some of the animals in the Felidae family.

Changes are still going on. They occur so slowly that we do not notice most of them. Sometimes we read about one in the newspaper. For example, one news report told about a new variety of insect that has appeared. The new kind looks like the old, but it is resistant to the sprays that man has been using against the old. That is, the spray is not deadly to the new variety.

These pictures show members of the Canidae family and the Felidae family. How are they alike? How do they differ?

Look about the room, and point out children with freckles, black hair, blonde hair, brown hair, and red hair, and tall and short boys and girls. Point out that these traits were all part of the makeup of their human ancestors.



Draw a diagram on the board or provide dittoed sheets with an outline such as the one above.

Since you know your class, be careful not to embarrass orphans, adopted children, and similar individuals. In classes where this would be a problem, take some public personage (a President of the United States, for example).

Ask, upon completion of the table:

- *In what ways are your brothers and sisters like you? How do you differ?*
- *In what ways are you like your mother? Father?*

Responses to the above should include all the aspects of physical appearance, habits, likes and dislikes, etc.

[illegible]
(pp. 332–333)

LESSON: What is meant by adaptation?

Learnings to Be Developed:

Adaptation is a key idea in biological science.

An adaptation is a change in the *structure* of an animal that makes it easier for the animal to survive.

There is a significant relationship between the structure of an animal and its behavior.

Developing the Lesson: Ask a child who has had experience training a pet to explain the procedure he or she used for a simple learning (e.g., teaching a dog to sit up). If the child cannot point out essential ingredients of training, attempt to do so for him by looking for such things as:

Need (usually for food) leading to awareness of the reward (food); if eventually the animal performs the desired act, he is rewarded almost immediately.

If punishment is used, point out that punishment, to be most effective, should be administered *immediately after* an improper act and should be used *sparingly*.

In human beings, the reward is frequently satisfaction in knowing that something can be done

Here you see three examples of how animals have adapted. Can you tell what adaptations these animals have made to their environments? How do these adaptations enable them to survive?

Adaptations of Animals

A change in the structure of an animal that makes it easier for the animal to survive is called an *adaptation*. Adaptation is one of the key ideas in the science of biology. The claws of the cat are adapted for climbing, and the legs of the dog for running. The long neck of the giraffe is adapted for eating leaves from the tops of trees. Would there be many other animals feasting on these leaves? How would the ability to reach so high for food help the giraffe to survive?

When we examine the many, many forms of animal life, we find examples of adaptation in each form. On a single tree, for example, there may be insects that are adapted for living only on the leaves. Others make their way into the bark or into the trunk of the tree. Some insects are adapted for living near the top of the tree, where there is more light. Others may live on the roots. How do these adaptations help them to survive? What would happen if all insects ate from the same part of the tree?

Changes in Structure and Behavior

With changes in structure, different behaviors are possible for an animal. With sharp claws a cat can climb a tree, while a dog cannot climb it. But dogs and cats are different in many other ways, as you know. Dogs tend to be friendly, sociable animals that are easily trained. They can learn to get along in many kinds of homes. Cats, on the other hand, are very "independent." They can be trained, but training is difficult. Just try to teach a cat to stay off the kitchen table!

Why the difference? The difference can be explained in part by the history of the animals. Members of the dog family—wolves, foxes, and others—are adapted to hunting in packs. They are good runners, and by hunting together they can chase a victim in circles, tiring it and making it easier to catch. Cats are built so that they hunt better alone. They cannot run fast for long periods of time. By lying in ambush, a cat can pounce on a victim and hold it with its sharp claws. This is a type of hunting that is best done by a lone animal. Most members of the cat family are adapted to this kind of hunting. House pets, of course, no longer need many of the skills their ancestors needed.

The history of how animals have adapted helps to explain differences in behavior. Dogs have a long history of being *social*, a behavior that goes along with their structure. Cats have an equally long history of *living by themselves*. Dogs and cats that behaved in these ways survived; others did not.

(throwing a curve ball or solving a problem in research). Raise such questions as:

- *Can you train* a cat *to talk?*
- *Why not?* (The mechanisms required to reproduce the wide range of sounds needed in human speech are absent in the vocal cords of cats.)

Psychologists think that the elephant probably has greater intelligence than the horse or the pig. Children probably have seen elephants that have been trained to do some very complicated tricks in a circus. In parts of Asia they are used as very skillful work animals. They pull loads and stack logs.

Discuss the adaptations illustrated on page 332. The giraffe's long neck adapts it to obtaining food from high locations and also enables it to sight enemies from afar. The cat's sense of balance and claws allow tree climbing. The horse has developed power and agility necessary for running and jumping.

TEACHING SUGGESTIONS
(pp. 334–335)

● **LESSON:** Are animals born with adaptations?

Learnings to Be Developed:
Scientists reject the notion that animals are born with instincts that will appear after birth as the result of an inherited blueprint; stimulation from the environment is necessary to release the behavior.

Developing the Lesson: Discuss the pecking and following behavior of ducks and chickens illustrated on pages 334–335.

You could introduce a pupil project here on "Learning in planaria." The planaria can easily be secured from a biological supply house.

Normally, a planarian does not immediately respond to changes in light in the same manner in which it reacts to an electric shock. It can be trained to do so, however.

You will need a 6-volt battery, some wire, and a strong light source.

Place a few planaria in a shallow saucer containing about $^1/_8$″ to $^1/_4$″ of water. Connect dry cells

Are They Born That Way?

Are dogs and cats born with their special ways of behaving, or do they learn these ways through experience? This is a question that has interested scientists for many years. There has been a great deal of research on animal behaviors to find the answer.

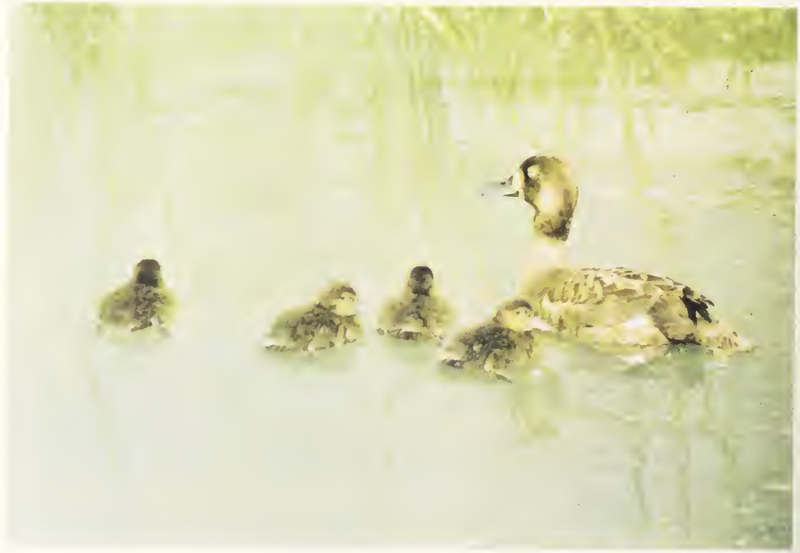
One kind of animal behavior that has been studied is *following* behavior.

Some animals, as you know, follow after the mother animal. Ducklings and lambs are two kinds of animal that do this. Can you name others?

Scientists used to think that animals were born with behaviors such as following behavior. They used to think these behaviors would appear no matter what happened to an animal after birth. But experiments have shown that this is not so.

In one experiment ducklings, shortly after hatching, were shown a wooden duck. The wooden duck was wired so that it could move. One by one the little ducklings fell in line behind it. A few days later they were put out in a pond. Their real mother was there, but they continued to follow the wooden animal.

Scientists have learned from experimenting and observing that animals that follow are not born with a follow-after-mother behavior. How, then, can it be



explained? Scientists continue to experiment to find answers. They also experiment with other behaviors, such as the pecking behavior of chicks. They have found that an infant animal must sense the proper *sign* at the proper *time*. It must see something or smell something or hear something or feel something—but it must be the right something at the right time.

In the case of the ducklings, the proper sign is any moving object; the duckling *must* see some object move. The message that something is moving is carried to the brain. In the brain, certain cells are stimulated. When the cells are stimulated, chemical messengers are released to other parts of the nervous system. Then the ducklings begin to follow.

The cells are sensitive to this special stimulation for just a short time. The 13-to-16-hour-old ducklings are at the best age to start to follow. If they are more than a day old before seeing a moving object, the ducklings are not likely to follow.

Remember that not all animals follow a moving object. A puppy or kitten does not follow its mother wherever she goes. An animal must be born with nerve cells that make this kind of behavior possible. Chemicals in the cells must be put together in such a way as to be stimulated by a certain kind of sign. Ducklings, goslings, and lambs are born with cells that can be stimulated when they see a moving object. Other behaviors require other kinds of signs for their release.

and bring a wire from the positive and a wire from the negative end into the water at opposite sides of the dish. The planaria will roll up or contract into a ball. When you remove the shock they will resume their normal, extended shape.

Now try the same procedure many times with a pause (of a few seconds) between each shock. Also flash a strong light simultaneously with each shock. Rest for about 15 minutes and repeat the series. Every so often flash the light without the shock and determine if the planarian has "learned" to contract without the shock. Keep track of the number of trials needed to train the worm.

Does the worm "remember" from one day to the next? Have pupils design an investigation to find out.

TEACHING SUGGESTIONS
(pp. 336–337)

● **LESSON:** What are some mating releasers in animals?

Learnings to Be Developed: Releasers, or signals, to which mature animals respond may affect the senses of sound, sight, touch, and smell.

Developing the Lesson: Recall experiences with the classroom pets to encourage responses to the lesson question above.

Discuss the following examples of releasers:

Odor: Dogs, hamsters, etc. sniff each other's hind quarters.

Sight: In some deep sea animals and in fireflies, luminescence and flashing are mating releasers. Male birds, such as the Maryland yellowthroat, can recognize pattern and color in the female, and vice versa. The mature female heron has red legs, and males are aroused by the leg color.

Sound: Crow calls, duck calls, and moose calls are all mating releasers. Grasshoppers and katydids vibrate parts of their bodies to attract mates and release mating behavior.

Touch: Earthworms are hermaphroditic, and it appears that a tactile sense is involved in mating.

Releasers

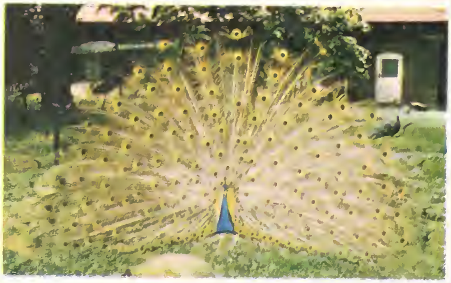
Whatever stimulates a kind of behavior is called a *releaser*. Ethologists are very interested in finding the releasers for particular behaviors. They look for something in one animal that releases a particular behavior in another of the same species. The releaser is like a key that unlocks the door to particular behaviors. It may be color, special markings, movement, odor, or sound.

Perhaps you have seen a male bird in the spring courting a female. Some birds put on quite a show, fluffing up their feathers and strutting about. What is there about the female that releases this courting behavior? The male does not strut about before another male. How does he know the difference between a male and a female?

An experiment was done with flickers. The male and female flickers look alike, except for the color of the moustache under the bill. The male's moustache is darker than the female's. Ethologists captured the female of a pair and dyed her moustache to match the male's. When she tried to go back to the nest, the male chased her away in fury. The dark-colored moustache close to the nest released fighting behavior, whereas the lighter-colored one had earlier released courting behavior.

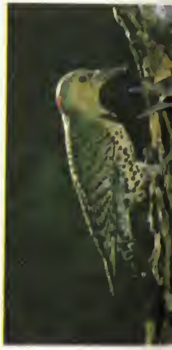
Remember how the male stickleback defended his territory from all other males? Males have a long, red belly. Females have a gray-colored belly, which is rounder in shape when they carry eggs. Ethologists made a dummy model of clay, rounded in shape but with a red belly. The stickleback attacked it. But when the red color was removed, he made gestures to invite the dummy into his nest!

The male peacock displays his brightly colored feathers to attract the female peacock.



Male flicker

Female flicker



Scientists are interested in the way in which behavior begins. They see behavior as resulting from what goes on between the animal and its environment. They think that what an animal inherits is like a picture that is not finished. The details are filled in as the animal responds to things in its environment. Scientists find patterns of behavior and then try to find out why and how and when these patterns appear. In their studies, they continue to search for the key ideas to help them understand animal behavior.

Using What You Have Learned

1. List examples of adaptation to environmental change, such as the ways bees are adapted to cold. How many other examples can you find?

2. Scientists have studied the ancestors of the modern horse. They have traced changes from very early ancestors. Prepare a special report on these ancestors, answering the following questions:

a. How did the earliest-known ancestor differ from the modern horse?

b. How do we know that such an animal existed?

c. What changes were there in feet, teeth, and size as offspring came along?

d. Why are there no longer animals like the ancestors of the horse? *

3. Find out more about how the behavior of dogs differs according to breed. People who raise dogs for sale usually specialize in one breed only.

Invite two people who raise dogs of different breeds to class. Ask each to tell about the behaviors of the breed he raises. Plan the questions you will ask under such headings as "playfulness," "getting along with people," "fighting," and "amount of activity."

** There appear to have been many genera descended from Eohippus besides the surviving horse of today, but all of these have become extinct.*

TEACHING SUGGESTIONS
(p. 337)

Background: The answers to *Using What You Have Learned* are:

1. This adaptation is one that changes environmental temperature. Bees keep their hives warm in winter by beating their wings. The temperature of the hive remains remarkably constant (31°–34° C.). As the temperature falls, bees cluster and beat their wings. Their body temperatures rise about 40° C. for a period until the hive is at needed temperature. Other examples might include hibernation, migration, estivation.

2. The earliest fossil horse is the Eohippus of the Eocene Epoch, which was about a foot high and had three hind toes and four front toes touching the ground. The Mesohippus, of the Oligocene Epoch, was twice that size, and ran mainly on its center toe. The larger Merychippus, of the Miocene Epoch, was about the size of a small pony; Pliohippus, of the Pliocene Epoch, was about 60 inches high, with a single toe becoming the main support on the ground. The skull form and the grinding teeth followed a similar development. The Equus is today's horse.

TEACHING SUGGESTIONS
(pp. 338–339)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned: This is a summary of the entire unit. with new words in boldface type.

Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390–393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

WHAT YOU KNOW ABOUT

How Animals Behave

What You Have Learned

Behavior means all the activities of an animal except those that are automatic. Scientists who study animal behavior are called **ethologists.** An ethologist searches for key ideas that explain behavior.

Animals have senses that tell them what is happening in the world about them. An animal's **sensory** equipment includes sensory receptors. These receptors are made up of cells that are sensitive to different kinds of information. The different kinds of sensory receptors include **chemoreceptors, photoreceptors, thermoreceptors,** and **mechanical receptors.**

Complicated animals have a **central nervous system** that consists of a spinal cord and a brain. The central nervous system **coordinates** the different parts of the body. Within the part of a mammal's brain called the **hypothalamus** there are control centers for appetite and temperature.

Animals have evolved during the course of millions of years. The adaptations of animals to their environments have made it possible for the animals to survive.

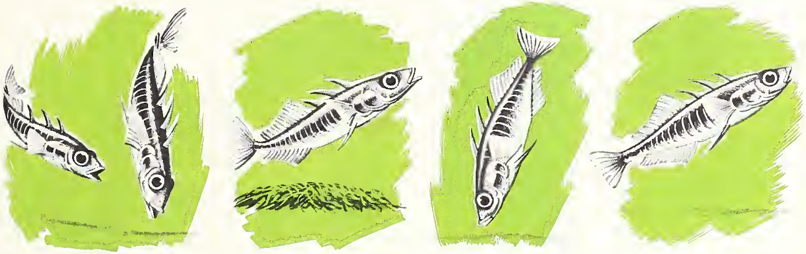
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

acclimatize	ethologists	mosaic
chemoreceptors	facets	photoreceptors
coordination	hypothalamus	sensory

Name the Key Idea

Look at the pictures below. For each picture tell what key idea about the stickleback's behavior can be applied to the behavior of other animals.



Matching Test

Write the numbers 1 to 9 on your paper. Next to each number write the letter of the word or words described.

1. Receptors stimulated by tastes and smells.
2. Receptors stimulated by light.
3. Receptors stimulated by changes in temperature.
4. Adjusted to a climate.
5. Receptors stimulated by touch, pressure, and sound.
6. The brain and the spinal cord.
7. Location of centers for temperature and appetite control in the mammalian brain.
8. A change in the structure of an animal that makes it easier for the animal to survive.
9. What sets in motion a response characteristic of that species.

A. releaser
B. hypothalamus
C. mechanical receptors
D. acclimatized
E. thermoreceptors
F. adaptation
G. chemoreceptors
H. photoreceptors
I. central nervous system

Name the Key Idea: Refer to page 305 for the five key ideas.

Matching Test:

1. G
2. H
3. E
4. D
5. C
6. I
7. B
8. F
9. A

TEACHING SUGGESTIONS
(pp. 340–341)

Background: These pages reinforce the concepts presented in the unit by suggesting activities that extend the pupil's ability to apply the learnings derived from the unit.

You may find the following books useful:

The Lower Animals: Living Invertebrates of The World, by Ralph Buchsbaum and Lorus Milne (Doubleday, 1960). Excellent descriptions and photographs.

Animal Behavior, by Vincent G. Dethier and Eliot Stellar (Prentice-Hall, 1961).

Echoes of Bats and Men, by Donald R. Griffin (Doubleday, 1960). Unusual study of bats and applications to radar and echo-location; paperback.

The Migration of Birds, by Frederick C. Lincoln (Doubleday, 1960). Paperback.

The Life of Birds, by Joel Welty (Knopf, 1963). Good introduction to bird study.

The Language of Animals, by Millicent E. Selsam (Morrow, 1962). Recent findings and methods of research in animal communication.

YOU CAN LEARN MORE ABOUT How Animals Behave

You Can Observe Color Changes in a Chameleon

Make a chameleon home as shown in the picture. Next, buy a green chameleon at a pet store or a science-supply house. Chameleons need live food such as mealworms, flies, and moths. Hang a bit of meat or fruit on a string to attract flies. Every other day sprinkle water on the plants in the chameleon home. The chameleons will drink the drops on the leaves. Place the cage where it will get a few hours of sunlight each day. Keep the temperature at about 80° F. In winter, place a 25-watt bulb in one corner of the cage. Make sure there are always some shady places in the cage.

Place the chameleon on green and brown cloths. What happens? Does the chameleon change color in response to temperature and light? Try taking the chameleon outdoors when the temperature is about 50° F. What happens? With the temperature indoors at 70° F., put the chameleon in a bright place. What happens? Place it in a dark place. What happens? Raise the temperature of the cage to 105° F., taking care that the environment remains humid. What happens?

Study the animal's appearance. How does its long tail help it to keep its balance? How do its long toes help it to run on branches? How does it eat? How does it drink? How does it compare with other reptiles? How is it adapted to living in trees?

You Can Visit

A good place to observe how animals behave is a zoo. Many zoos have exhibits in which animals roam woodlands and plains in settings very much like the environments in which the animals naturally are found. Zoos also try to provide the animals with diets and temperature conditions similar to those found in nature. To find the zoo nearest to you, write to your local chamber of commerce.

You Can Read

1. *Winter-Sleeping Wildlife,* by Will Barker. The life cycles of animals whose activities slow down at certain times of the year.
2. *The Strange World of Animal Senses,* by Margaret Cosgrove. Tells how various senses are combined in an animal to enable it to survive in its environment.
3. *Animal Habits,* by George F. Mason. Tells about instincts, communication, and other behaviors of animals.
4. *Animal Behavior,* from the Life Nature Library. A well-illustrated book on animal behavior and the kinds of research that have been done on animals to study behavior.
5. *How Animals Live Together,* by Millicent E. Selsam. Tells about animal relationships.

Additional Readings:

The Wonders of Life on Earth, by Lincoln Barnett and The Editors of *LIFE.* (Golden, 1960). Darwin's theories of evolution, the effects of heredity and environment, Mendel's experiments, and DNA.

How to Understand Animal Talk, by Vinson Brown (Little, 1958). Comprehensive, authorative discussion of animal communication.

Animal Clocks and Compasses, by Margaret O. Hyde (Whittlesey, 1960). Award-winning study of animal instincts, with some basic information on time and the Theory of Relativity; suggestions for projects.

Animal Tools, by George F. Mason (Morrow, 1951). Specialized appendages and organs and their functions; clear style, excellent illustrations.

Films:

Adaptations of Insects (13 min., color, Stanton Films).

Butterfly (6 min., color, Coronet). Life cycle of an insect.

Earthworms, (11 min., color, Pat Dowling Pictures).

Fish Family (10 min., color, Moody Institute of Science).

KEY CONCEPTS

Key Concept 1. Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

Key Concept 9. The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

CONCEPTS:

1. Scientific knowledge is growing at an increasing rate.
2. Science today plays an important part in the lives of everyone.
3. Bionics is the science that copies nature.
4. Scientists are attempting to find new ways of using the energy produced by living organisms.
5. Cryogenics is the science that investigates the behavior of matter under super-cold conditions.
6. Scientists are investigating ways in which laser beams can be used to advance scientific knowledge further.
7. Many advances are being made in the science of ultrasonics.

9

Other concepts appear under "Learnings to Be Developed" in each lesson found in the Teaching Suggestions.

Science–Today and Tomorrow

Science in Today's World

Bionics—The Science That Copies Nature

Biopower—Energy from Living Organisms

Cryogenics—The Supercold World

Lasers—Light Brighter Than the Sun

Ultrasonics—The Sound You Cannot Hear

You and Science for Tomorrow's World

8. There are many interesting scientific careers available to young people today.

PROCESSES:

- Selecting— Pages 349, 366, 369, 384, 385.
- Communicating—349.
- Explaining—349, 369.

TEACHING SUGGESTIONS
(pp. 344–346)

● **LESSON:** How does science affect your life?

Learnings to Be Developed:
Scientific knowledge is growing at an increasing rate.

Science has improved the living conditions of man.

Science has created problems.

Man has learned in the past that solutions and adaptations must be made to ensure survival.

The problems growing out of scientific discovery are no longer the problems of the scientist alone.

Developing the Lesson: Use a brief outline of man's biological and social history as a starting point for discussion.

You might want to explore the idea that today's discoveries are dependent on the work of others.

• *What ideas developed by Isaac Newton make rocket flight to the moon possible?* (An object in motion tends to remain in motion at the same speed and in the same direction unless something outside itself changes direction or motion. Gravitational forces of the earth and moon were explained by Newton also. These all have effects on lunar flights.)

Galileo, Copernicus, and others started a revolution in science that continues today with an almost unbelievable flow of new knowledge. Scientific and technical information pours from universities and research laboratories. The scientific revolution is shaping your world of today and tomorrow.

Science in Today's World

Scientific knowledge has been doubling every ten years since about the middle of the eighteenth century. You have available 8 times as much knowledge as your father had, 64 times as much as your grandfather had, and over 1,000 times as much as your great-grandfather had.

Every year, over a million and a quarter research reports are published in the biological and physical sciences.

Even more amazing is the increase in the number of scientists and in the number of scientific careers. Ninety per cent of the scientists who have ever lived are alive today!

Suppose we drew a graph of scientific advances made from the dawn of civilization to the year 1945. If we plotted the rising curve so that it reached a height of 4 inches for 1945, we would need a chart as tall as a

Here you see only an armful of the more than one million research reports published each year. How many areas of science can you identify in the reports shown?

How do these two results of modern science affect the world in which you live?

thirteen-story building to plot the progress from 1945 to 1960! From 1960 to today and into tomorrow, the curve moves ever upward. How high will it reach? How great is man's desire for knowledge?

Science in Our Lives

Today, science is a part of almost everything we do and see. Some of the results of modern science are easy to see—rockets, nuclear-powered ships, jet airliners. Some other results of modern science are not so easily seen—the clothes we wear, the amount and kinds of food we eat, the way we live together in cities, the healthier, longer lives we lead, and many other things.

Modern science has changed the way man thinks about himself and the world in which he lives. Once man lived in constant fear of hunger, pain, and death. Man's food supply depended on acts of nature, which he believed were controlled by the gods. Great plagues wiped out families and whole villages without warning. When lightning and raging winds struck, man thought he was being punished for his sins.

Science has reduced man's ignorance and helplessness. Even when man has not yet been able to control the forces of nature—such as hurricanes and tornadoes, or unconquered diseases such

- *Then why did we not have lunar travel years ago?* (Man knew the forces and speed necessary to accomplish a trip to the moon, but was not able to produce enough contained power to carry a spaceship away from the earth's gravity.)

Hero's Engine was devised hundreds of years before steam trains and boats.

- *When was the steam engine developed for use?* (James Watt developed the modern steam engine in the late 1700's.)

Attempt, with the class, to prepare a developmental list of discoveries, e.g., amber and static electricity, leading to Volta's work with electricity, leading to Faraday's work, leading to radio, radar, and television.

Pose problems such as:

- *Identify items in this room that would have been absent from a schoolroom of Louis Pasteur. Do the same for the home.* (Not only items but materials of which they are constructed should enter the list.)

After a discussion of pages 344–346, have the children cite as many examples as they can of problems that arise in their daily living that did not occur in Abra-

ham Lincoln's time. Such examples might include:

My outdoor plastic pool keeps turning green.

During a storm the freezer went off and the ice cream melted.

I had to wash dishes last night. Something went wrong with the dishwasher.

ADDITIONAL ACTIVITIES:

Prepare for future work in this chapter by setting up research committees to gather current information from general magazines and newspapers covering one week's time. Committees could be arranged according to agriculture, electronics, medicine, space, conservation, meteorology, astronomy, archaeology, communication, and geology.

Invite a high school librarian or public librarian to give a talk on the problems of keeping track of science information. Request that he or she bring examples of some technical journals.

Have pupils whose families include professional people working in the sciences ask their parents to borrow samples of literature, including house organs and journals. Make a display for the class or school entitled: "Reading Materials for the Scientist."

as cancer and the common cold—man now feels that he knows a great deal about them and that soon he may be able to control these too.

The discovery of the microscope led men to find the causes and cures of many diseases. Discoveries about electricity led to the invention of the radio, the telegraph, the telephone, television, power generators, and other devices. Once the doors to scientific knowledge were opened there was a flood of discoveries and inventions.

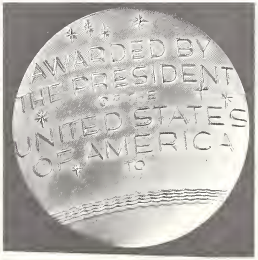
In 1866, someone suggested that the United States Patent Office, which registers inventions, might soon shut down, since everything would surely have been thought of. But instead, more and more ideas—new ideas—came. Today, ideas come at an even greater rate as new discoveries lead to more knowledge of our world and new knowledge leads to new discoveries.

Today our country and other advanced countries support scientific endeavors and reward achievement. In 1964, Nobel Prizes in physics, chemistry, and medicine—the highest awards in science—were given to two Americans, two Russians, an Englishman, and a German. In 1965 the United States Congress awarded 11 scientists the National Medal of Science. All these men and women are pathfinders in the science of today.

In this unit you will read about five of the many new branches of research in science and about some of the scientists who are pathfinders in the science for tomorrow's world.

The Nobel Prize, shown on the right, is awarded to the world's outstanding scientists.

President Lyndon B. Johnson presents the 1965 United States National Medal of Science. As a project, find out about the contributions made by the winners.



Using What You Have Learned

1. In 1638, Galileo published a book called *The Two New Sciences*. In so doing, it is said that he changed man's idea of nature and thus triggered the scientific revolution that has shaped today's world. Can you explain this statement?

2. Who was Alfred Nobel? What is the purpose of the Nobel Prizes?

3. Make a chart to show how various discoveries such as the microscope, the telescope, and the germ theory of disease sparked new knowledge and understanding of man and the world in which he lives.

4. How is scientific achievement rewarded in countries such as Great Britain, France, and Russia? Why is it important to reward such achievement? Find out how citizens can support scientific work.

TEACHING SUGGESTIONS

(p. 347)

Background: The answers to *Using What You Have Learned* are:

1. A quotation from another of Galileo's works, *The Dialogue*, might help. "I wrote this book in the vernacular because I want everybody to be able to read it." He abandoned the Latin in order to spread knowledge. In addition, he was not content merely to observe and record. He began to measure and to analyze his measurements. He was not the first to study quantitatively, but he did it extensively and with such literary ability that his quantitative methods were fashionable and famous.

Galileo's refusal to base a study of nature on the word of past authorities further enhances his stature as a researcher. He accepted only experience and observation as the basis for conclusions.

2. Alfred Nobel was a Swedish inventor (1833–1896), whose most famous invention was dynamite, a mixture of nitroglycerin and diatomaceous earth. His purposes for the invention were peaceful, but other uses were soon found. Nobel left a fund of over nine million dollars to establish prizes in the fields of peace, medicine and physiology, literature, chemistry, and physics.

TEACHING SUGGESTIONS
(pp. 348–352)

● **LESSON:** Can science copy nature?

Background: *Audio location.* (Echo location has been studied in insects, bats, and other nocturnal animals in order to discover, if possible, how they find their way in the dark.)

The bat utters repeated high-pitched cries (40,000 vibrations per second) and hears echos of these sounds reflected from objects in its path. The bat's hearing is such that he can distinguish between the echoes of "insect" (food) and "branch" (obstacle). The exact nature of the vibrations and the means that the bat uses to receive and translate the returning signals would be very useful for the design of instruments for the blind, for ships in fog, and for airplanes. Some information has already been of help in designing radar and other man-made echo-location devices.

Computers. The design of computers is based on mathematics. There is an analogy between computers and the nervous systems of living organisms. All computers pick up bits of information from sensitive *receptors* and send these *impulses* to a central point where they are coordinated with other

Bionics—The Science That Copies Nature

A bat can fly through a dark room strung with dozens of piano wires and not touch even one of them. A snake can react to changes in temperature as small as 1/1000 of a degree. By vibrating its wings, a mosquito can set up a hum that will signal another mosquito 150 feet away even when thunder roars or fire engines' sirens scream. How can animals do these things?

Scientists have long been interested in these animals. They have tried to find out about the special equipment that enables a bat to sense objects near it. They seek the sense organs that enable a snake to detect very small changes in temperature. And they want to know how a mosquito is able to signal through loud noises.

Scientists believe that finding the answers to these questions may lead to many important inventions. In 1960, a new branch of science was born. Lt. Colonel Jack E. Steele, a flight surgeon in the United States Air Force, gave the name *bionics* to this new branch of science. **Bionics**, like biology, is the study of life. But bionics scientists, or bionicists, study life for a special reason. They study living systems to find out what makes them work. With this knowledge, engineers may be able to copy these living systems.

Lt. Colonel Steele is a physician who studies living systems to find out what makes them work and then uses the knowledge he gains to try to improve man-made systems.

Bionics uses a *team approach* to research—biologists work with others.

Making a Copy of Nature

Let us see how a copy of nature might be made. There are two tasks involved. The first is to find out how an animal's body or part of a body works. Suppose researchers want to find out how a frog's eye works. First they track down the connections from

A frog's eyes screen out every movement that is not important to its own life. Scientists study the frog's eye to learn how to develop, for example, an air-defense system that is better than radar.

The frog sees many things, shown here in symbolic form. Its brain screens out all but the one important to its survival.

eye cells to brain cells and try to understand what goes on within them. The second task is for engineers, mathematicians, and others to try to duplicate what has been learned from the model made of the living frog's eye. Bionicists are working in a very new science, but already they have had some successes. The study of birds has given bionicists answers to important questions about the shape and curve of bird wings, and the bionicists have been able to apply this knowledge to improving the design of aircraft wings.

How might the study of birds enable scientists and engineers to improve the design and manufacture of airplanes?

information. *Memory* devices perform acts similar to reflex actions in animals, and a *response* is emitted by the computer.

Because electronic computers can store and recall information quickly, they are a necessity for many aspects of modern science.

Learnings to Be Developed: Bionics is the science that copies nature.

Developing the Lesson: The bat's ability to perform perceptual acrobatics, mentioned on page 348, is well documented in *Echoes of Bats and Men* by Donald R. Griffin. While not identified as being about bionics, this book is a fine illustration of man's mind applying itself to the question "What can I learn from animals?" It explores more, in its 96 pages, than the title indicates.

Another springboard for discussion of this new science would be to indicate that it is new in name but in reality had its start years ago. Borrow a copy of *The Notebooks of Leonardo da Vinci* from your library. Use a projector to show to the class the many drawings indicating that da Vinci first studied animal structures and then designed objects to perform similar functions. Bird wing studies are followed by crude aircraft. Studies of fish bladders are followed by crude designs for submarines.

Catapults are designed following diagramatic studies of the lever principle in human and animal bones.

Other examples of man's copying nature can be found in the principles of streamlining.

- *Compare the formation of flying geese and the shape of a bullet.*
- *Compare the shape of a fast-swimming fish such as a shark with that of a submarine.*

Find other pictorial examples of streamlining in nature and similar streamlining designed by man.

Perhaps your school has a teaching machine. Call upon its custodian to explain the function and work of the machine. Review the ideas of learning from Unit 8 and indicate that human learning has been studied by psychologists. The psychologists have found out many things concerning how humans learn. Together with engineers they have designed machines that help train other human beings. Indicate that this type of teaching is in its infancy, and we still do not know how best to use it. Scientists are trying to improve the machines now in use.

○**ADDITIONAL ACTIVITIES:**

Have a group of pupils design a question-and-answer box using electric wires, a small light bulb,

Scientists studying communications have been studying the dolphin. They believe that the dolphin uses sound navigation. Tape recordings have been made of dolphin whistles, clicks, barks, and jaw-clacking noises. The picture below shows rubber suction-cup discs placed over each eye of a dolphin. The dolphin cannot see this way and must rely totally on its senses of hearing and sonar-sounding to find its way.

Fish gills are being studied so that better underwater breathing equipment for humans can be designed. Much research is being done to find out how the dolphin—a mammal—swims as fast as it does. Scientists believe that the structure of the dolphin's skin may help his swimming. Now they are experimenting with a rubberlike coating for boats the texture of which is very much like that of the skin of the dolphin. Perhaps this coating will lessen the drag on boats moving through the water.

Scientists doing research in communications are also studying the dolphin. Its ultrasonic whistling has been found to be a form of communication among dolphins. Perhaps ways will be found to adapt this technique so that it can be used for underwater signaling among humans, or even for communication among humans and dolphins and other living things.

A beetle's eye has already been used as a model for a device to make better ground-speed indicators for aircraft. Ground speed is the velocity of an airplane, for example, with relation to the surface of the earth. The beetle's two-part eye lets it judge its own speed. One part of its eye sees an object before the other part sees it. The time interval tells the beetle how fast it is going.

In copying the beetle's "indicator," Air Force scientists use two electric eyes—one in the nose of a plane, the other in the tail. In place of the beetle's brain, they use a small electronic computer.

A cockroach can detect movements of only millionths of an inch much better than any present man-made device. How does it do this? Finding out may help scientists make their present instruments more delicate and precise.

Scientists have made mechanical "noses," based on what they have learned about the sense organs of animals, that can "smell" very faint odors. Such devices, if they can be made as efficient as animals' noses, may help warn of dangerous gases and spoiled foods.

Joining Living and Artificial Systems

Scientists are also attempting to join together living and artificial systems. An example of this is a system in which an astronaut is attached to a type of booster that operates his arms for him when he is under such great forces that he is not strong enough to move his arms. The booster uses signals from the astronaut's muscles to control motors for moving his arms. There are uses for such a system in space and in very cold or very hot environments,

and a dry cell. Some of these available as toy games are simple enough for pupil construction. They could be used as a simple analogy to a nervous system.

Secure a picture of a "hot cell" from a Brookhaven National Laboratories or another atomic laboratory. Analyze the picture to see the relationship between the mechanism for manipulating radioactive materials from afar. The lever arrangement, similar to the finger-and-arm arrangement of humans, enables the operator to remain outside the radioactive room and move chemicals and objects within the room.

The Bell Telephone Laboratories have designed an artificial larynx for the use of people whose voice box has been removed or who are mute. Your local Bell Telephone office can supply you with information and perhaps a speaker on this topic: How man copies nature in designing a voice box.

Bell Telephone also has a record that you can borrow from local business offices on "Computer Speech." This short record illustrates how a computer was used to construct human speech. It is worth playing for your students. It will spark many questions related to bionics.

TEACHING SUGGESTIONS
(pp. 352–355)

● **LESSON:** Can the energy of living things be used by man?

Background: Perhaps historically we should mention an Italian anatomist first as the discoverer of a biocell. In the 18th century Luigi Galvani (1737–1798) was attempting to find out if a frog's leg would twitch in a lightning storm. (He suspected it would after Franklin showed lightning to be electrical in nature.) He hung the leg muscles of a frog on brass hooks and rested them against an iron lattice on his window. During the thunderstorm they did twitch — but they also twitched before and after! Unknowingly, he had discovered an electric cell. Alessandro Volta some years later proved that the acids of the muscle in contact with two different metals produced electricity. The Voltaic cell was born. (For additional material on Volta, see *Science for Tomorrow's World*, Book 4, pages 152–153.)

Learnings to Be Developed: Scientists are attempting to find new ways of using the energy produced by living organisms.

where people are unable to move their muscles normally. Such a system may also enable people who have lost the use of their arms and legs to move about. Artificial limbs might also be more useful with boosters.

Bionics, the science that copies living systems, is providing a two-way exchange of valuable results. The engineer is learning to make better artificial systems from his study of nature, and the biologist is learning more about his subject, living systems, from the work of the engineer. Bionics will lead to a better understanding of the world in which we live.

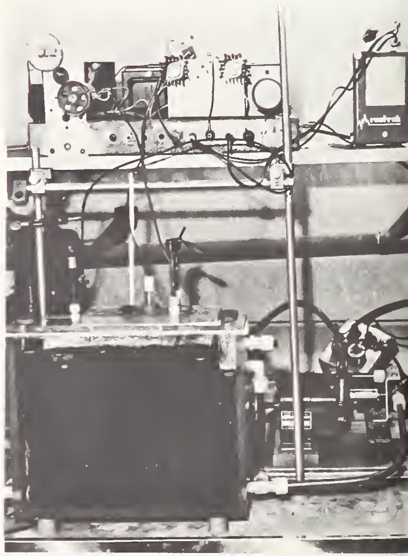
Biopower—Energy from Living Organisms

Imagine an electric battery made up of bacteria! Imagine a radio transmitter powered by this battery. Does this sound like science fiction? Indeed it is not! In 1962 a team of scientists generated practical amounts of electricity from living organisms and put it to use. The radio transmitter they demonstrated had a range of only 15 miles, but scientists were as excited by it as if its range had been millions of miles.

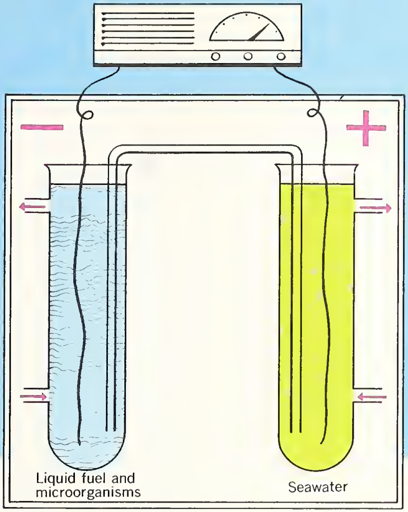
The Biocell

This new power supply is called a **biocell.** Using a liquid fuel and microorganisms such as bacteria, a biocell changes chemical energy directly into electrical energy.

All living things are really biocells. The difference between a living thing and a man-made biocell is that the fuel



The biocell at the bottom of the picture was used to power the radio transmitter above it.



This diagram shows how the biocell works to produce energy to power a radio transmitter. Can you trace the flow of electrons that produces the electrical circuit?

in a living thing gives off energy in the form of heat instead of in the form of electricity. The scientist's task is to cause the "burning" of fuel by an organism and then change the heat given off into a flow of electrons—that is, current electricity.

This process is very much the same as changing chemical energy to electrical energy in the simple battery or voltaic cell. Two different elements such as zinc and carbon are placed in a water-and-acid solution. The zinc is called the negative pole and the carbon is the positive pole. The acid attacks the zinc as if it were burning it. As electrons flow from the zinc of the negative pole to the carbon of the positive pole, energy is given off in the form of electricity.

The biocell is more efficient than the voltaic cell. In the biocell described on page 352 that powered the radio transmitter, Dr. Frederick Sisler, a scientist, used bacteria for the negative pole of the cell. The bacteria were in a test tube, as were sea water and other material for fuel. The positive pole contained sea water and oxygen. The electrons moved from the fuel (negative pole) through an electrical circuit to do the work.

Developing the Lesson: In order to understand the operation of a biocell, review the activities of Unit 3, particularly the explanation of electric cells on pages 99–100 of the pupil text.

Ask pupils to compare the diagram of the biocell on page 353 with the diagram of the chemical dry cell on page 117.

- *What are the points of similarity?* (Two poles, one negative and one positive; a flow of electrons from one area to another within the cell; a substance to cause an imbalance and thus a flow; need for a circuit in both to do work.)
- *How are they dissimilar?* (In the energizing agents: acid and zinc in the dry cell, water and bacteria in the biocell.)

Discuss the advantages of biocells as outlined on page 354. Ask:

- *How would you use such cells if they were available in your home?* (Heavy-power items could not be run by such small-power units.)

ADDITIONAL ACTIVITIES:

Some organisms exhibit electric behavior that is biologically induced. A study of such phenomena may be of use to mankind.

Have pupils do library research on the electric eel and electric ray. The organisms have specialized disc cells in their muscles. When stimulated, these cells build up a voltage of hundreds of volts for a short period. This build-up is released in a fraction of a second and is used to stun small fish or kill them.

The electroencephalograph (EEG) and the electrocardiograph (EKG) are electrically produced graphs of brain and heart activity that give an indication of the behavior of the brain or heart. The graphs are studied by a doctor to discover more about the health of an individual.

Have some pupils do research on this area. The interactions of millions of nerve cells in the human cerebral cortex produce small electrical voltages. These extend through the skull and scalp. Similar neurological activity occurs in the region of the heart.

Note: The fact that animal tissues exhibit electric phenomena is not too remarkable. Animal tissues have an abundance of electrolytes (acids and bases), and the balance and strength of these is in constant flux.

Advantages in Using Biocells

What advantage does the biocell have over our present ways of producing electricity? The biocell can draw energy *directly* from living things, which our present electrical generators cannot do. When you flip the switch on a lamp to light a room, you are using electrical energy that comes *indirectly* from living things. Fuels such as coal and oil, produced from living things, are burned and give off energy to change water to steam. The steam runs a turbine that drives a generator, and you have electricity to light the room. About 66 per cent of the energy produced is lost.

The biocell, however, changes chemical energy *directly* into electrical energy. In this process, only about 25 per cent of the energy is lost.

How might a biocell be used? One way is to produce electricity cheaply. The Black Sea might make an excellent fuel source, since its water is rich in the bacteria needed. Dr. Sisler and his team of scientists have already developed a model boat that cruises in a tank of water using electricity generated from the water itself.

Biopower seems to be available from just about any source you can imagine. The United States Bureau of Mines has developed a biocell that uses oxygen from the air as fuel. Other scientists have developed a biocell that uses algae, one-celled plants, as a burnable fuel. Algae, through the process of photosynthesis, can absorb sunlight to change carbon dioxide and water into carbohydrates. The carbohydrates are then used by bacteria as food or fuel. The bacteria change the carbohydrates back into carbon dioxide and water. In this process, the bacteria generate electricity. This system continues as long as solar energy is available. It might be a good source of electricity for space

This do-it-yourself biocell kit uses a sawdust-like material and bacteria for building a twelve-cell biochemical battery.

flights through our solar system, where the sun always shines.

Biocell power packages have been developed to operate ship radio beacons. These models are about the size of automobile batteries and can produce several watts of power.

Work is now under way to use biopower for manned spaceships. In a spaceship, a biocell using algae would change waste materials into air, water, and food for the astronauts. It would also provide electrical energy for operating radios and other equipment.

The biocell is now being developed as a producer of electricity for radios, light bulbs, space capsules, navigation buoys, and other uses. Scientists believe that one day the biocell will produce power at a price that will be the same as that of standard generators. Its big advantage will be that it will use materials that would otherwise be nothing but waste. If biocells can be operated on sea water, sawdust, air, sunlight, and sewage, we may have an almost inexhaustible source of energy. We would no longer be dependent on fossil fuels, such as coal and oil, that we use today. Science for tomorrow's world may use energy from living things —biopower.

Cryogenics—The Supercold World

A few years ago, some scientists slowly lowered a metal ball over the center of a metal ring. As the ball was lowered it seemed to become lighter and lighter. Suddenly, it stopped its movement downward and floated just above the ring—with no visible support.

The scientists said the ball could float there forever. Quite a trick? It is only one of the many unusual things that can take place in the supercold world of **cryogenics** (kry-oh-JEN-ikss). *Cryogenics* comes from two words—*kryos*, for "icy cold," and *generare*, which means "to make."

The science of cryogenics deals with temperatures near absolute zero—minus 459.7° F., or minus 273.2° C. Over a hundred years ago, the British physicist Lord Kelvin stated that, according to his mathematics, at these temperatures the molecules of which matter is made would theoretically stop their motion. This point, said Lord Kelvin, would be absolute zero.

How cold is absolute zero? The lowest natural temperature recorded is minus 126° F., in Antarctica, and this is over 300° warmer than absolute zero!

TEACHING SUGGESTIONS
(pp. 355–359)

● **LESSON:** What has science learned about supercold substances?

Background: The theoretical science that is extending the frontiers of man's knowledge is challenging to the scientific fraternity; it should be an inspiration to youth. The field of cryogenics is in its infancy. Many of the phenomena presented in this section are still unexplained. The subject should be presented as a challenge to the future — the world that sixth graders will meet as they grow up.

Learnings to Be Developed: Cryogenics is the science that investigates the behavior of matter under supercold conditions.

Developing the Lesson: The description of the metal ball and ring on page 355 should be read by the pupils. Before proceeding, ask:

- *What force could cause the ball to float?*

Accept all reasonable responses that might account for the bizarre behavior, such as antigravity, electricity, magnetism, cold itself (remember that heat induced the flow of electricity — Unit 3), etc. Ask each respondent to justify his answer by presenting evidence. Do not comment on the value of the answers, but let the final

answer develop as the discussion progresses through page 357.

Background: Cryogenic temperatures are usually considered to be those below the boiling point of liquid oxygen (−183° C.).

When a substance becomes a superconductor, its resistance to electron flow is reduced to zero. The conductor is 100 per cent efficient.

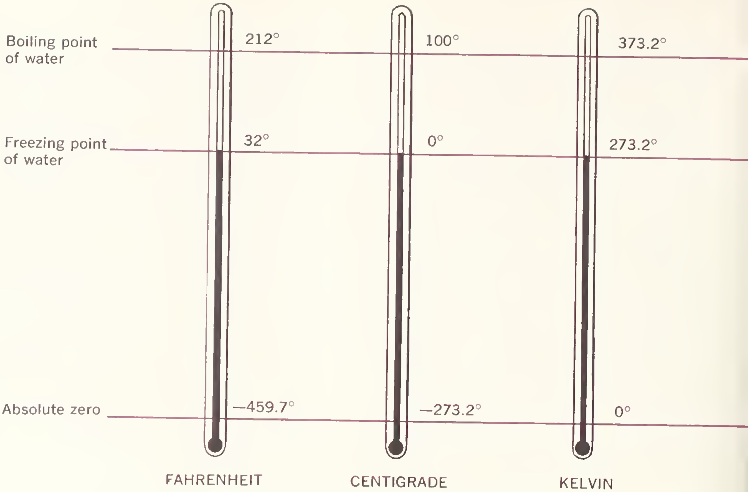
The superconducting temperatures of some materials are:

Lead	−266° C.
Helium	−268° C.
Aluminum	−272° C.
Tin	−268.5° C.
Titanium	−272.5° C.

The diagram on page 357 should serve to refresh the pupils' memories concerning the kinetic theory described in Unit 2, Heat and Molecules.

ADDITIONAL ACTIVITIES:

Have the class secretary write to the Cryogenic Laboratory, National Bureau of Standards, Boulder, Colo., and request answers to such questions as: Why is the government interested in cryogenics? How are gases such as hydrogen brought to a liquid state? How are they stored?



This illustration shows three scales of temperature measurement.

Superconductivity

The experiment with the metal ball demonstrated the phenomenon of **superconductivity** (soo-per-kon-duk-TIV-uh-tee). This is a characteristic of certain metals when they are cooled to near absolute zero.

To learn more about superconductors we must go back over fifty years to the work of Heike Kamerlingh Onnes, a Dutch physicist. In 1913, Onnes won a Nobel Prize for producing the coldest temperature that was known to man—minus 272° C., or almost absolute zero.

Onnes went on to discover that once he started an electrical current in supercold mercury, electrons continued to move around the circuit without ever stopping. He did not know why this occurred, nor did anyone else. But scientists since then have found many other superconductive materials.

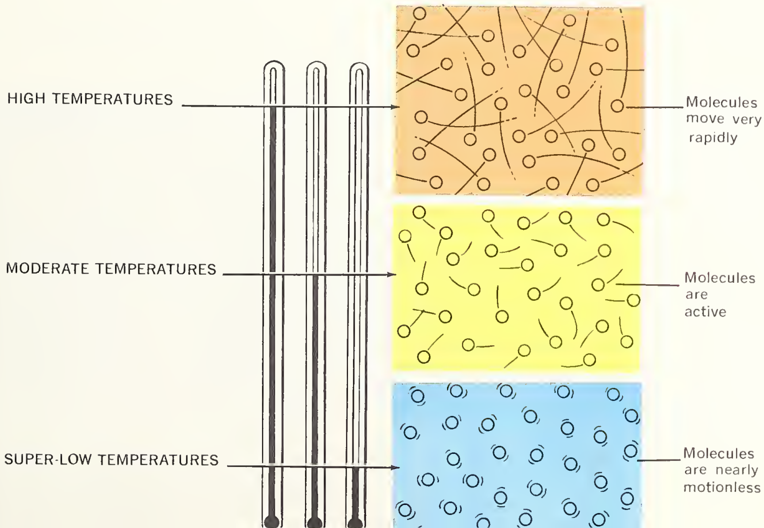
Materials such as lead, aluminum, uranium, and titanium can become superconductors. At temperatures a few degrees above absolute zero, electricity meets no resistance in these materials, and the current seems to circle endlessly in the circuit.

Superconductors as Magnetic "Mirrors"

Later discoveries showed another strange phenomenon of metals in a superconducting state—they *repelled* a magnetic field. The explanation is that a magnetic field builds up certain "currents" in the metal. These currents create an identical, and therefore opposing, magnetic field. Superconductors are in effect magnetic "mirrors." To understand this effect better, let us go back to the ball-and-ring experiment. Both the ball and the ring were cooled to the point where they had become superconductors. A current was set up in the ring, creating a magnetic field around the ring. As the ball was lowered, the magnetic field in the ring built up currents in the ball. The ball produced its own magnetic field, which repelled that of the ring—just as like poles of bar magnets repel each other. The result of the experiment was that the ball floated above the ring.

How might scientists apply this phenomenon? They can produce a frictionless bearing. A bearing is used to

This diagram shows the effect of heat on metals. Electricity does not flow well through metals at high temperatures. Electricity will flow well through certain metals such as silver and copper at moderate temperatures. Electricity flows very well through certain metals such as lead and tin at super-low temperatures. What relationship is there between the movement of molecules through a metal and the flow of electricity?



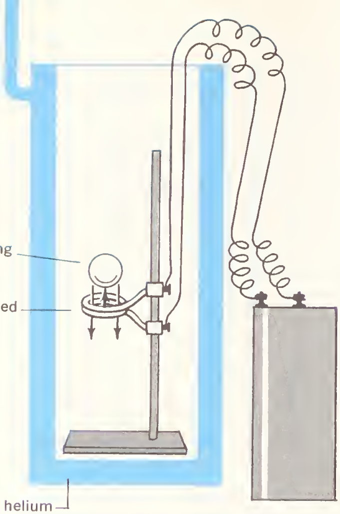
One type of cryogenic equipment is similar in operation to a refrigerator. The principle involved is easy to demonstrate. Tell each child to hold his hand close to his mouth and breathe out slowly with his mouth wide open. Notice the warmth. Now have him hold his hand as before but pucker his lips to a small opening and force the breath out in a stream. It is cooler?

The operating principle used here is based on the fact that compressed air escaping through a small opening gets cooler when it expands into a larger volume. If you have an aerosol can, the same phenomenon can be experienced. Compressed air emits heat and expanded air absorbs it (because it is cooler). By having a compression chamber outside the "refrigerator" and the expansion chamber within, heat is constantly removed from the "refrigerator."

- *How cold can we get something in this room?*

By using an immersion thermometer, a metal can (a 1-lb. coffee tin should do well), and some crushed ice mixed with salt, you should be able to get temperatures well below -15° C.

Have pupils measure the temperatures of the refrigerator, home freezer, and air conditioners in their homes and report their findings. How far away is the lowest recorded temperature from absolute zero?



The ball and the ring were cooled to the point where they became superconductors. What happens when a current is set up in the ring?

support or guide moving parts. It is the part of a machine which *bears* the friction when the parts are in contact and moving. The ball bearings in roller skates greatly reduce the friction produced by the turning wheels. Look at a pair of skates and you will see how they work. Notice that the bearings are in contact. Friction produced by the wheels is less than if there were no bearings. A superconductor bearing would have no physical contact between surfaces. Such a system is superior even to air bearings, since the superconductor can function in a vacuum and eliminate the drag even of air.

Because of the remarkable properties of cryogenic superconductors, devices have been developed that include generators, magnets, motors, switches, transformers, and computer parts. Can you tell how cryogenic superconductors might be used in each of these devices? How would you go about finding the answer to this question?

Superfluids

Just as some metals can become superconductors, some liquids can become **superfluids** at cryogenic temperatures. These superfluids show some unusual properties. One of these properties is known as "creep." Liquid helium, for example, creeps up and over the walls of its container, and finally empties itself from the container. You can see this happening in the picture on the next page.

At a few tenths of a degree above absolute zero, oxygen and nitrogen change from liquids into solids, looking like snow.

Cryogenic liquid oxygen and other gases are being used in liquid-fuel rockets. Liquid oxygen is also being used in place of high-pressure tanks of oxygen gas in the storage of breathing oxygen for aircraft and submarines. Can you tell what advantage the liquid oxygen has over the high-pressure tanks?

Other Uses for Cryogenics

The science of cryogenics enables scientists to produce the temperatures of outer space, which may be close to absolute zero, so they can try to develop better fuels and new metals that are able to withstand these temperatures. Cryogenics also permits scientists to build better electronic and other equipment needed for guiding space flights.

Cryogenics has also branched out into **cryobiology**, for work with living tissues, and **cryosurgery**, in which operations such as repairing the retina of the eye are performed with probes cooled by liquid nitrogen.

Cryogenics holds great promise as a part of tomorrow's world.

Challenge pupils to design objects that could benefit by frictionless bearings. Encourage fantasy in this instance as a mind-expanding activity.

Have children write a science fiction story, poem, or play around the ideas presented in this section.

In each picture you see the phenomenon known as "creep." On the left, a scientist experiments with superconductivity to create very strong magnetic fields. How do technicians who work with liquid gases for rockets protect themselves?

TEACHING SUGGESTIONS
(pp. 360–362)

● **LESSON:** What is a laser beam?

Background: Actually, the work of an American physicist, Charles H. Townes, resulted in the laser's being developed. The laser's predecessor (the maser) was much more significant from a scientific point of view, but, its invention and use were less spectacular. The maser did not attract the eyes of many newspaper science writers, but it did confirm Michelson's work on the speed of light (see pages 198–199).

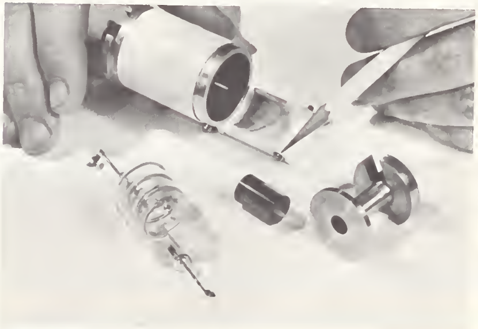
The maser was a device used to amplify signals from *Echo I*, an early communications satellite. Microwaves are radio waves in the range of radar. The step from microwaves to light waves was a fairly simple one, and Townes and his students made the step after 7 years of work.

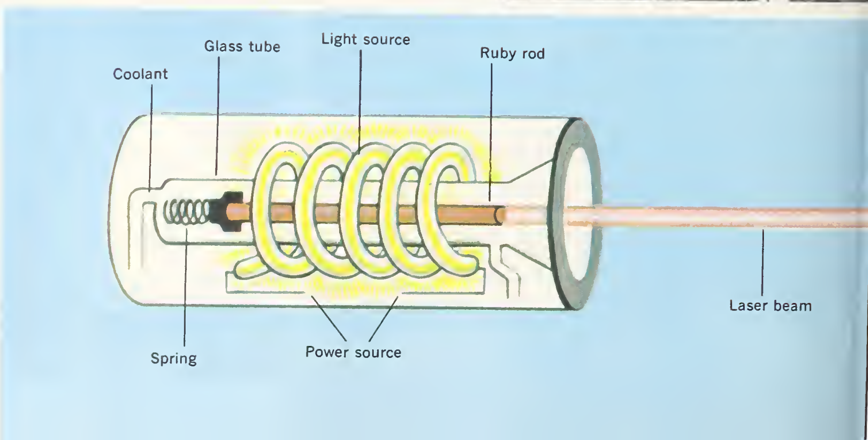
Unlike the beam of the flashlight mentioned on page 261, the laser's ruby-red light beam is *coherent;* it maintains a straight beam and does not follow the inverse square law mentioned below. Another important feature is that it emits a wavelength that is purely monochromatic — all the waves are of the same wavelength. Flashlights emit light of mixed wavelengths.

Lasers—Light Brighter Than the Sun

A ruby rod about half the size of a pencil is bathed in bright light coming from a coiled glass tube of xenon gas. The tightly packed atoms in the ruby are excited by the light, which they amplify into an intense beam. This beam is the **laser,** developed by Dr. Theodore H. Maiman in 1960. The word *laser* is made up of the first letter of each word in the name: *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation.

Dr. Theodore H. Maiman studies the equipment needed to produce a laser. Below, you see a diagram of the materials used to produce a laser. You can get an idea of how small the parts of a laser are by looking at the picture on the left.





The laser is far brighter than the sun. Lasers can burn holes through diamonds, bounce beams off the moon, transmit television pictures, weld metals, perform surgery on the human eye, and kill cancerous growths. Because lasers can travel for great, great distances, they can seek out galaxies at the edge of the knowable universe. Possibly they may be used as a means for human beings to communicate with the creatures of other worlds—if they exist.

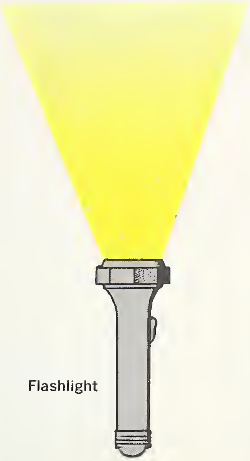
A Laser Moonshot

The laser beam goes in only one direction, unlike the beam of a flashlight, which fans out and is cone-shaped. A flashlight's beam is a steadily enlarging cone, as shown in the picture.

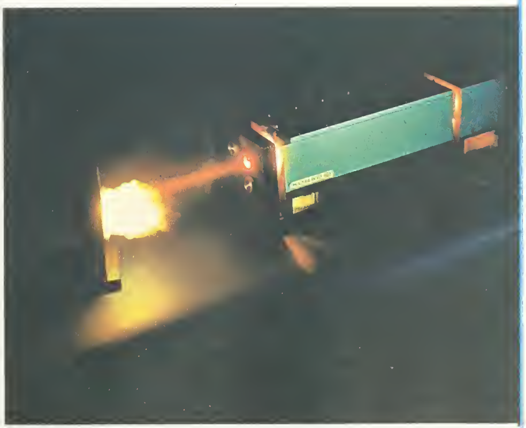
Searchlights send out their light in ever-widening beams, as do flashlights. If a searchlight beam were powerful enough to reach the moon, its light would cover a circle 25,000 miles in diameter. Can you tell why a searchlight beam cannot be reflected back to earth from the moon?

In 1962 scientists at the Massachusetts Institute of Technology fired a laser burst at the moon. The beam that hit the lunar surface was only a *few* miles in diameter and was reflected back to earth. The narrow beam of the laser is one of its most important properties. In this narrow beam is a tremendous concentration of energy. This is why it can burn holes in diamonds.

The searchlight's beam widens in a cone.



Notice the narrowness of the laser beam.



Because the laser beam is of a single wavelength, the communications industry is most interested in its ability to carry messages. It has been stated by an expert in communication that its potential is such that if modulation can be built into it, a single ray could carry all the messages in the world today in two directions simultaneously. This statement is based on the laser's vibration rate of over 24 billion times a second. The laser has greater communication possibilities than radio has today.

Learnings to Be Developed: Scientists are investigating uses for laser beams.

Developing the Lesson: Review the wave theory of light, since light waves are amplified by the laser. The amplification is analogous to making water waves higher, not more numerous.

Ask, to start the lesson:

- *Is a flashlight brighter near the lamp or at a distance?*
- *What happens to the light as it travels away from the source?* (It spreads out and becomes less intense.)

If your class appreciates the meaning of inverse ratio or inverse proportion, you might introduce the

inverse square law here. *Light intensity diminishes by the square of the distance from the source.* At 2 feet from the source, light is 1/4 as bright as at 1 foot; at 3 feet, it is 1/9 as bright; at 4 feet, 1/16 as bright; etc. This could be checked as an activity later, or the class could be led to discover the relationship.

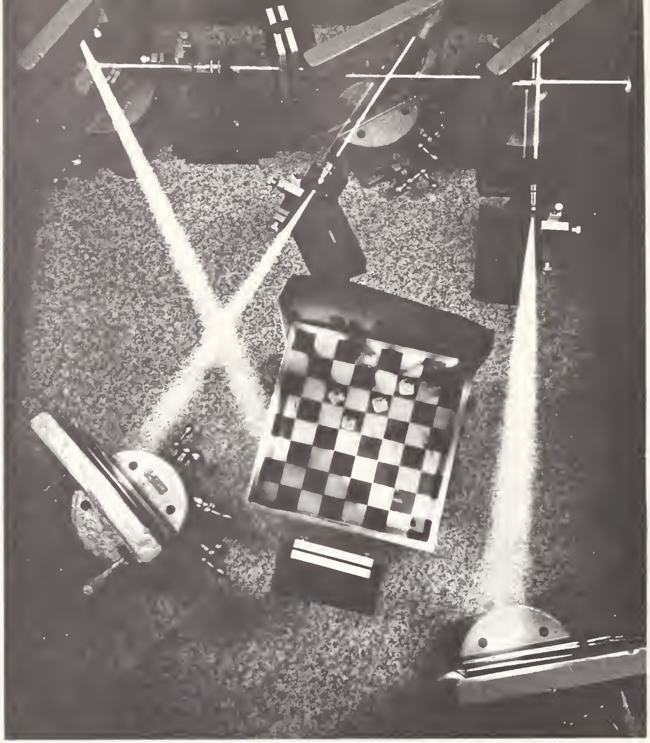
Read and discuss the technological aspects of lasers on pages 360–362).

ADDITIONAL ACTIVITIES:

Analyze light waves using a diffraction grating or a triangular prism. Discuss wavelength.

Design an investigation of the inverse square law as it applies to light. Use a photographer's light meter to get readings from a floodlight at distances over a series of units; 2 feet, 4 feet, and 8 feet would be adequate. With a less intense bulb, readings at 1, 2, 3, and 4 feet should be adequate to establish your relationships. Consult a high school physics book for design of a more accurate investigation.

Assign library research on Charles H. Townes and John R. Pierce as well as Theodore Maiman.



Lasers have been used to take photographs. Here you see laser beams set up to take photographs of a chess game.

Other Uses for Lasers

The laser may play a role in electronic computers. Research is under way to make circuits using light beams instead of wires. To join separate computers thousands of miles apart, telephone lines or radios are now used, but laser "light pipes" may one day take their place.

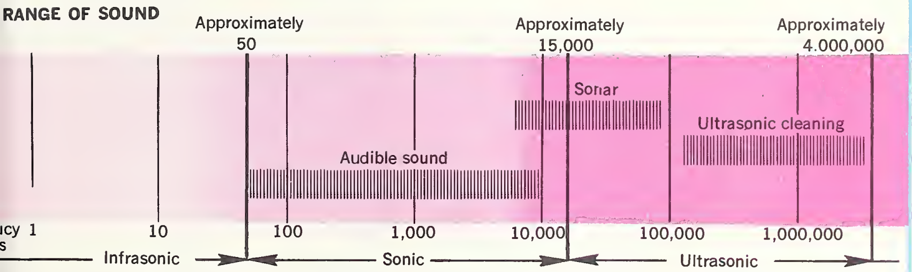
The laser is a scientific achievement that in a short span of years has become one of the most exciting new instruments in scientific research for tomorrow's world.

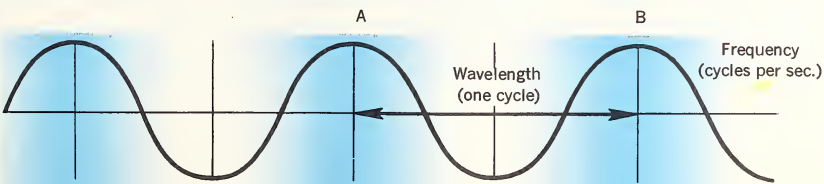
Ultrasonics—The Sound You Cannot Hear

Imagine washing dishes and clothes with sound, making scrambled eggs right in the shell with sound, or perhaps tenderizing food or cleaning watches and surgical instruments with sound. These are just a few of the many uses for ultrasonics—the silent sound.

What is silent sound? Have you ever used a dog whistle? If you have, you know that *you* cannot hear the whistle. Yet your dog must, because he reacts when you blow it. So we know there are sounds that we cannot hear. **Ultrasonics** is based on the same principles as those of the sound waves we can hear. Sound, as you have learned, is a vibration that takes place in a medium such as air, water, or solid material. The vibrations make a wave that passes through the material without causing the material to move. Man's ears are sensitive to certain vibrations. The sound we hear lies in the range of 16 to 20,000 cycles per second. Above and below that range is ultrasound.

Sound is measured by its frequency, which is given in cycles per second. A cycle is one complete wave. If a sound wave has a frequency of 15,000 cycles per second, this means 15,000 waves pass a given point each second. If the frequency is less, fewer waves pass the given point in a given time. Wavelength is the distance from any point on a wave to the same point on the next wave, as from A to B. The more rapidly something vibrates, the higher the frequency and the shorter the wavelength. Can you tell why?





TEACHING SUGGESTIONS
(pp. 363–366)

● **LESSON:** Can man use sounds that he cannot hear?

Background: One of the earliest investigators of ultrasonic sound was Pierre Curie, who, with his brother, discovered that the application of pressure on certain crystals produced a flow of electricity and, conversely, that by applying changing voltages to the faces of these crystals they could make the crystals vibrate rapidly. They succeeded in 1880 in producing an ultrasonic beam. (Pierre married Marie Curie 19 years later and abandoned this line of work to carry on radiation research with her.) Some years later another French scientist, Paul Langerin, continued Curie's research on ultrasonics and eventually produced a technology which led shortly before World War II to sonar. In sonar devices, ultrasonic waves are used for the detection of submarines, ocean floor surroundings and mapping, locating schools of fish, etc.

Learnings to Be Developed: Many advances are being made in the science of ultrasonics.

Developing the Lesson: The previous study of lasers and this on ultrasonics should be related to the general idea that many forms of energy travel in waves. The study of such waves is part of wave mechanics.

In order to give a stronger basis for understanding *ultrasonics,* it might be advisable to refresh the children's ideas concerning *normal* sonics. After a reading and discussion of page 363, ask:

- *How do you hear me ask questions? In other words, what receptors do you have for collecting the sound waves coming from my vocal cords?*

If possible, have a large chart or model of the structure of the human ear available. The outer ear collects sound waves and directs them to the eardrum. A series of three small bones picks up and transmits the vibrations of the drum membrane to an inner ear structure called the coch*l*ea. The bones act as levers to amplify the vibrations and concentrate the vibrating force on a tiny window in the cochlea. The cochlea contains over 30,000 receptors sensitive to mechanical vibrations. These receptors are embedded along the inner spirals of the cochlea and are surrounded by a fluid. The vibrations on the window produce pressure changes, which stimulate

Focusing Sound Waves

Just as light waves can be focused, so can sound waves. Listening devices using reflectors can focus sound. Sound can be both reflected and focused. The science of ultrasonics uses these properties of sound in devices such as microscopes and telescopes that use sound waves instead of light.

Sound waves also affect the material they move through. For example, jet planes have caused sonic booms, which have cracked windows and damaged buildings. Sonic boom is caused as sound waves pile up ahead of jet planes as the planes travel faster than the speed of sound.

The Advantage of Ultrasonics

Why do we not use the sound we hear rather than ultrasonics? One important reason is noise. If the power needed for ultrasonic devices could be heard by human beings, it would probably drive us out of our minds and perhaps harm us in other ways. The advantage of ultrasonics is that the sound cannot be heard.

Ultrasound has been used in the sea to find enemy submarines. *Sonar,* which stands for *so*und *n*avigation *a*nd *r*anging is a device that sends out sounds underwater from a boat at regular intervals. The sound moves through the water until it strikes the

This machine cuts by means of ultrasonics.

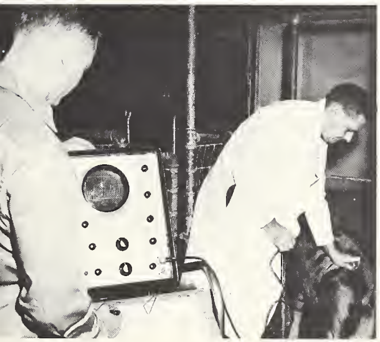
bottom—or a school of fish, a submarine, or something else that is solid. Part of the sound is reflected and picked up aboard ship on the device. Since the speed of sound through the water is known, it is easy to measure the distance to the object by the length of time it takes for the echo to return to the ship.

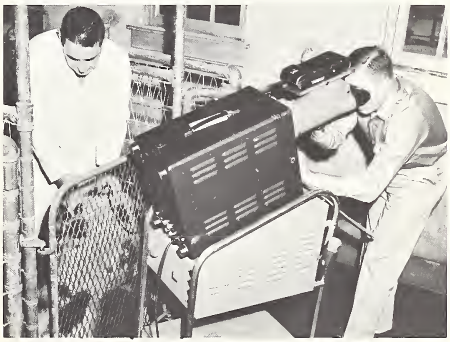
This reflection idea is also used on land. Are you able to tune your

These parts have been put together using ultrasonic methods.

television set by means of a wireless remote control? It is probably an ultrasonic device. Some automatic garage doors respond to an ultrasonic whistle on a car. Ultrasonic alarms can be used to spot faulty products on an assembly line. These alarms can also be used in buildings to detect rats or burglars. Ultrasound is used to find faults in metal, glass, and rubber parts. It can measure the flow of liquids in closed tanks. Ultrasonics can also be used to assemble the parts of instruments. The photograph on the left shows some completed instruments. Can you tell how sound was used to assemble them? Ultrasonic cutting and grinding tools and drills are used on hard-to-work materials. One such device is shown on page 364. Ultrasonics has been used to homogenize peanut butter and tenderize meats and frozen foods. Ultrasonic devices also check cattle for their content of lean and fat. Two ways in which such devices are used are shown below.

Scientists use an ultrasonic device to measure back fat on a live hog. On the right, such a device is equipped with a camera to make a photographic record of the tissue depth.





the receptors. These in turn send impulses to the brain.

Certain nerve endings are affected by low-frequency vibrations; others are affected only by high frequencies.

- *Can human ears be stimulated by all vibrations of the air?* (No.)
- *From what you know about sound waves, explain why not all vibrations can be "sensed" by humans.*

You might compare the human ear to a radio. The usual AM radio can pick up frequencies of a restricted band, but it cannot pick out the frequencies of short wave, radar, or television. Its mechanical receptors are not "sensitive" to such vibrations. Similarly, the human ear has a restricted range. We actually produce air vibrations by simply waving a hand back and forth three or four times a second. No audible sounds are produced because the low limit for our ears is about 20 vibrations per second. Air vibrations below this frequency are called *infrasonic* waves.

The upper limit of audibility for most human ears is in the neighborhood of 20,000 vibrations, or cycles, per second. Vibrations above this limit are called *ultrasonic*.

Recall, in this connection, the use of the terms *ultraviolet* and *infrared* when you discussed light waves.

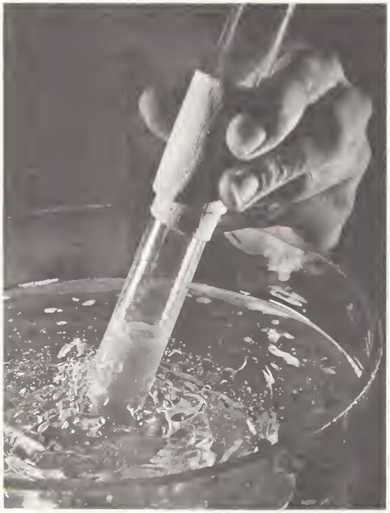
The human ear is most sensitive to sounds within the frequency range of 2,000 to 4,000 cycles per second. The complementarity of the human ear and voice should be brought out here as an instance of complementary adaptations, since the frequencies of the human voice range between 100 and 7,000 cycles per second.

Inaudible sounds fall outside the 20–20,000-cycle range. Man has contrived to use some low-frequency (infrasonic) vibrations to his advantage in drilling oil wells. The use of *ultrasonics* has been more widespread and has greater potential, since there seems to be no upper limit to the possible frequencies.

Cleaning with Sound

Ultrasonic equipment can create a churning effect in water. This effect is used to clean things in tanks by producing heat. Everything from watches to hypodermic needles can be cleaned better than ever before with ultrasonic cleaning. Test models of ultrasonic dishwashers and clothes washers have been made. They have proved to be successful. The problem now is to bring down their cost so that they can be used in homes.

Ultrasonics is used to stir and mix two substances, such as water and mercury, that under ordinary conditions do not mix.



Ultrasonics in Medicine

Medical scientists have used ultrasonics to relieve pain from arthritis and other ailments. They have also used ultrasonic methods to soften scar tissue around joints so that it can be flexed almost normally.

The ultrasonogram, a picture taken with sound, is being used to diagnose illnesses in the way that X rays are used. There are advantages over X rays. First, there is no danger from radiation. Second, the soft tissues of the body can be "seen." X rays do not show the soft tissues as well as they do hard (bone) tissue. Ultrasonograms are not so sharp as X-ray pictures, but improvements are being made. One day we may have ultrasonic microscopes that will be capable of showing us objects more clearly than light microscopes can.

Other Uses for Ultrasonics

Experiments are now being done on using ultrasound to remove soot and fog from the air. Chasing away unwanted birds, harmful insects, and other pests is another way in which ultrasonics is used.

On the left, you see another use for ultrasonics.

The possibilities for the use of ultrasonics seem as limitless as the scientist's and the engineer's imagination.

Using What You Have Learned

1. As you read about the new branches of science, were you aware of how many areas of science were brought together in each new branch? For example, bionics brought together biology, electronics, chemistry, and physics. What fields does the laser combine? What fields does ultrasonic research bring together?

2. Some other new developments in science are the solar battery, electronic computers, and ground-effect machines. Find out about each of these developments, and write a report on them. What are some good ways to find out about new developments in science?

3. Make a sign that reads *Science—Today and Tomorrow*. Place the sign on your classroom bulletin board. On this section of your bulletin board pin newspaper and magazine clippings of new science developments. Change the display each week. Perhaps you will have room enough to divide the board into sections for biology, chemistry, geology, physics, and any other areas that interest you.

You and Science for Tomorrow's World

You have now read about five new branches of science. You will learn more about these and other new branches as you go further in science in school. You will also find out more from books, newspapers, television, and radio. As you go further in science, you will find that all the science information you learned in your earlier school grades is necessary for you to understand what is happening today and what will be happening tomorrow in science. For example, you need to understand light before you can understand the laser. And you need to know the properties of sound before you can understand ultrasonics. The science you are now learning is helping to prepare you for the science for tomorrow's world.

TEACHING SUGGESTIONS

(p. 367)

Background: The answers to *Using What You Have Learned* are:

1. Laser development required the fields of chemistry (the maser utilized the chemistry of amonia molecules), crystalography (ruby crystal), electronics (microwave study), physics (wave motion), and optics and light behavior (the coherent nature of its beam). All fields of science cooperate in exploiting the laser for medicine, atomic studies, industrial cutting, space probing, and communications.

Ultrasonic research combines investigations in the biological sciences (echo location in animals and human hearing), physics (wave behavior), chemistry (solutions), food chemistry (hydrogenating oils and homogenized milk), and oceanography (sonar).

2. The best way of keeping up with new developments in science is to subscribe to science magazines. The *Science News-Letter* and *Science World I* are suitable for the pupils, while *Scientific American*, *Natural History*, *The New Scientist*, and *Science Journal* (the latter two are published in England) are more advanced.

TEACHING SUGGESTIONS
(pp. 368–370)

● **LESSON:** Why study science?

Background: One of the great needs of our present-day civilization is for scientific "literacy" – that is, a basic understanding by all of our citizens of the importance of science in their lives. We might even call this an *appreciation* of science in our lives, much as we apply the term "music appreciation." Science enables you and your family to live longer and better.

Learnings to Be Developed: There are many interesting scientific careers available to young people today.

Developing the Lesson: Two excellent references should prove valuable here. Morris Kline, in his *Mathematics and the Physical World,* traces many basic scientific ideas that can be understood even by a reader with only sixth-grade mathematics. You might want to investigate the ideas behind Mendelian theories of inheritance, the origin of the periodic table, binary computers, the work on blood circulation by Harvey, and Galileo's work on falling bodies.

William C. Vergara's *Mathematics in Everyday Things* should be available for the children.

Why Study Science?

Many of you will not become scientists, and you wonder why you should study science. The answer is simple. No matter what career you decide on, your knowledge of science will enable you to understand better the world in which you live.

We live in an age of science. Science can provide us with marvelous tools for the solution of many of the problems of both our physical and our social world. The work of scientists shapes the life of every human being on the earth. It will affect the future of generations to come. Both our lives and our livelihoods depend very greatly on science.

The Place of Mathematics in Science

If you are interested in any scientific field, whether it is wildlife management or nuclear physics, you will need to study mathematics. You cannot get along in any area of science without mathematics.

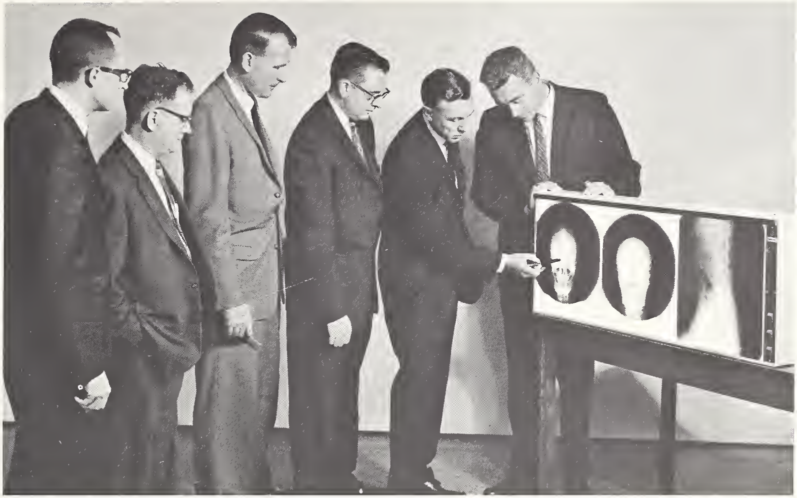
You may remember that in the fourth grade you learned that scientists use mathematics in comparing things. In the fifth grade, you learned about the theory of probability and how the scientist uses it in testing ideas. Again you needed mathematics. Earlier you learned that one important way of the scientist was measuring things, and again you needed mathematics to help you understand. Do you now see why mathematics is essential to the understanding of science?

The Science Team

The six men in the picture are all members of a research and development team that produced an improved X-ray system. This system produces sharp images even though the amount of time a person is exposed to radiation is 80 per cent less. The new system will enable radiologists (X-ray specialists) and others to do a much better job of medical diagnosis. But the really interesting thing about this story is that not one of the six men was trained in medical science.

These experts work at General Electric's X-ray Department in Milwaukee, Wisconsin. There are a physicist, an electrical engineer, an industrial designer, an economist, and a mechanical engineer among the six. When they were your age, they did not know where their studies would lead them. Even when they were in college they had no idea they would someday help to advance medical progress.

There are thousands of such teams in industry, research, and government. Their projects range over designing and launching spacecraft, building an arti-


These six men, all trained in different fields, worked together to develop the X-ray system shown. Many kinds of training are needed for today's science.

ficial heart, and developing toothpastes to prevent cavities.

Because so much is being learned about the world in which we live, a team of specialists in different fields is needed to work on most research projects.

Careers in the Biological Sciences

Biologists may work in the country, in the city, in a university, in an industrial plant, or in a hospital, among other places. Their work is as varied as the forms of life found on earth. Some biologists work in laboratories, using microscopes and test tubes, surrounded by animal cages, flower pots, or cultures of microorganisms. Others can be found on oceanographic vessels exploring the oceans. Still others may be found tracking rare animals and plants in the jungle or the Arctic, or exploring fields and woods.

If you like working out-of-doors, remember that the United States Fish and Wildlife Service employs many biologists, as does the United States Department of Agriculture, which needs soil

Before entering into discussion of various career opportunities, you could again pose the questions:

- *What is science?*
- *What is a scientist?*
- *How do scientists work?*

The dictionary definition of science simply may be "a body of organized knowledge." If we treat science as simply a pool of information, then this definition is adequate. But the far-reaching influence of scientific inquiry requires far more explaining.

Try to organize the children's answers into aspects such as:

Science is a body of ideas concerning the way the world works. Review the ten Key Concepts found in the teachers' guide.

Science is a body of tested information that we can use to live an intelligent and better life. For example, knowledge of heat activity led to development of air conditioning and house heating systems. Such inventions fall in an area of applied science called *technology*.

Science is a body of many methods to arrive at evidence. For example, experimentation.

A *scientist* is a person who uses the methods of science to increase

knowledge about our universe or any part of it. His *methods* are many. Aspects of the methods of science include:

Common sense.

Trial and error.

Chance discoveries — but chance discoveries that happen to people who are prepared to realize their significance, not just luck.

Planned experimentation to test guesses.

Occasional flashes of genius — by far the rarest method, but also one of the most significant.

Discussion, reading, thinking, organizing new relationships, searching for hidden orderliness in seemingly unrelated facts.

○ **ADDITIONAL ACTIVITIES:**

List some things for which they have no explanation at present.

- *Which do you think scientists will eventually explain?*
- *Which do you think will always be beyond explanation?*

Have pupils list what they consider the 5 greatest scientific feats.

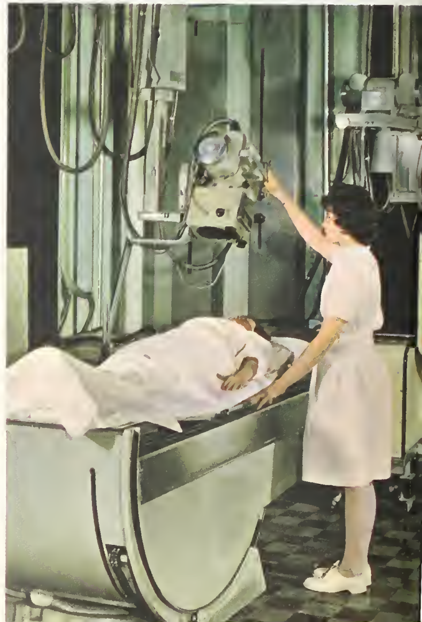
Astronauts must "unlearn" some of their habits. Have pupils list some of these habits and how scientists might help the astronauts "unlearn" and learn anew

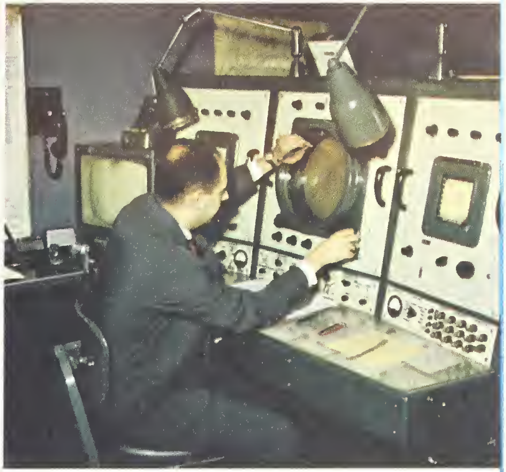
scientists and conservationists. Foresters are needed by government agencies and by lumber and paper companies.

To be a biologist you must have a college education. However, there are also many opportunities if you have a high school diploma and some specialized training. You can become a technician in the biological sciences. A histological technician prepares tissues for microscopic examination. A cytotechnologist examines cells for cancer. A medical technologist carries out chemical, microscopic, and other tests in hospital laboratories. An X-ray technician is trained to take X-ray pictures. You may also become a physical therapist. A therapist, under the supervision of a physician, applies treatments such as exercise, massage, and heat to patients. There is also a great demand for surgical technicians, who assist in hospital operating rooms.

With college training you can become a physician or a dentist or, if you like to care for animals, a veterinarian. If you are interested in drugs, you can become a pharmacist. Perhaps you would like to be a registered nurse—a field open to men and women.

A bacteriologist studies a Petri dish culture. At bottom left, a biologist uses an electron microscope. On the right, a technician prepares to take an X-ray picture.





A radiochemistry specialist measures the radioactivity in a substance. At the right, a meteorologist uses radar to observe certain weather conditions.

Careers in Physical Sciences

Would you like to work out the direction of a rocket flight as a space physicist? Perhaps you would rather investigate the structure and properties of metals as a solid-state physicist. Or maybe you are interested in being a geophysicist and exploring the earth and its magnetic field. Would you like to work with radioactive substances to discover better ways to fight diseases like cancer? Then you might be very happy as a chemist.

Perhaps you would enjoy studying the oceans, rivers, rocks, and ores. That is the job of the geologist. Exploration geologists use their knowledge to search out valuable mineral and oil deposits. Engineering geologists try to overcome natural obstacles that bar the way for the building of highways, tunnels, dams, and airfield runways.

Are you interested in the weather? Then perhaps meteorology may become your choice. Today's weather watchers are highly trained scientists. Would you rather probe outer space? A career in astronomy offers many opportunities for young men and women.

TEACHING SUGGESTIONS
(pp. 371–379)

LESSON: What careers are related to science?

Learnings to Be Developed:

Every science career has problems to solve.

Each career has its own area of interest and required abilities.

Developing the Lesson: After reading each section and discussing the implications of children's questions, ask the children to present some problems for which they would like answers in each science field. Some of these will already be solved, some are being worked on, and some problems might be unsolvable.

Biological science problems:

How can we learn new things more easily?

What causes cancer and how can we cure it?

Can the human mind communicate with others without our usual senses' being involved?

Is there a practical way to provide living plants to space travelers for their food and oxygen needs?

Can man develop a resistance to radiation hazards?

Physical science problems.

Will we ever know in advance what the weather will be?

Can we tap the oceans for water supplies for use in arid regions?

Can a laser be used for communications in a practical and economical manner?

Will we ever be able to see an atom?

Is there life on Mars? Venus?

Will we ever be able to convert atomic energy directly into electricity or into a device that will run an automobile?

Engineering problems:

Can we design a cabin for space travel that will provide artificial gravity?

Is a nonrusting steel possible?

Are underwater cities possible?

Can we make a safer, stronger car?

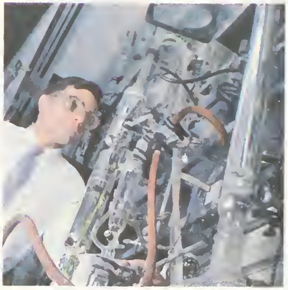
What improvements can be made for improved commuter transportation?

Can we make refrigerators and freezers smaller and yet able to hold more food?

What airplane design changes could contribute to safer travel? More comfortable air travel? Faster air travel?

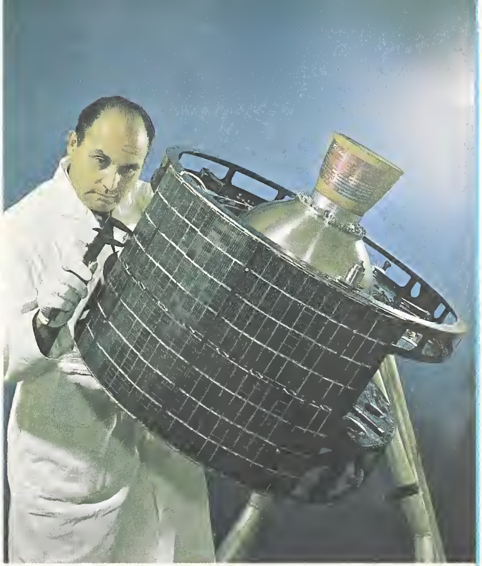
Physicists, chemists, astronomers, geologists, and meteorologists all must have college educations and usually at least three years of education beyond college. But there are many opportunities in the physical sciences for those who do not go to college.

Next time you watch a rocket flight take-off on television or in the movies, notice how many people are involved. A great many of these people are aerospace technicians, who are not scientists but nonetheless are important members of the scientific team.



An astronomer makes an adjustment on a giant telescope at an observatory. On the left a chemist looks at a maze of glass tubes to see results of his experiment.

A scientist explains a design to aerospace technicians. Each of these men is an important part of the space science team.



An electronics engineer makes a measurement on a satellite he helped to develop. Engineering offers many career opportunities.

Here is a list of just a few careers in the National Aeronautics and Space Administration (NASA): rocket systems firing test technician, optical instrument specialist, scientific photographer, spacecraft inspector, modelmaker, pressure suit mechanic. NASA has many training programs to equip young people with skills for the space program.

Each technician plays a vital role. Without the technician, the world of science would have a difficult time advancing as fast as it does.

Careers in Engineering

The engineer's job is to find usable solutions to problems. He likes to build things and watch them work. There is a great demand for young men and women engineers. And there is a variety of jobs.

For example, would you like to investigate biopower? Biochemical engineers experiment with biocells to find ways to generate electric energy with bacteria. Biomechanical engineers study weightlessness in space, problems

Science-related careers have important functions. Bring out that while primitive man could live a fairly isolated existence, today the interrelationships of any individual and his society are extremely complex. The work of scientists depends on a supporting cast. To bring home the point of man's dependence on others, ask the question:

- *On whom did you depend today?* (At home: The power line for the alarm clock, toaster, etc.; the farmers, truckers, processors, stackers, clerks, and advertising men responsible for your meals; parents for hundreds of things; tailors, oilmen, gasmen, etc., for home maintenance. At school: The bus driver, traffic police, and transportation office; principal and office personnel for supervision, teachers for instruction, writers for text materials. The list should be extensive.)

○ **ADDITIONAL ACTIVITIES:**

If your class or school has a newspaper, organize one issue as a science issue. If you do not have such a publication, organize the pupils to develop and produce one science issue. You can assume the rights and duties of publisher. The class could be divided into "scientists" in various fields, editorial staff, and writers.

Have reporters interview the "scientists" and report their interviews. The "scientists" should each become very familiar with a single aspect of science studied this year.

A "science teacher" could write a short article on "How I prepared for teaching science."

A pupil interested in photography could be a science photographer by taking appropriate photographs or searching out appropriate photos from magazines.

An art editor could illustrate the most appropriate articles.

One or two science book reviews should be included after consultation with a local librarian (science information specialist).

Collect high-quality photographs from magazines and organize a file on careers in the sciences.

Make a library search of such fields of study as archeology, paleontology, speleology, cytology, morphology, parasitology, etc. Which of these fields of study are "pure" science and which are applied sciences?

Have the pupils attempt to solve the brain teasers listed on page 375.

in the design of artificial organs for human beings, and even traffic safety.

Chemical engineers invent the processes for and design, maintain, and operate plants that manufacture insecticides, industrial chemicals, nuclear fuel, explosives, drugs, detergents, and many other products.

Electronics engineers work on a wide variety of problems from designing communications satellites to making phonograph records.

Civil engineers deal with the loads and stresses of the space age, finding out, among other things, how buildings react to sonic boom.

There are many other kinds of engineers. All engineering fields offer a bright future to young people who want to become a part of the advancing frontier in science.

Science-Related Careers

To help those who are not scientists understand the science of today and tomorrow is the work of another team of specialists. This team brings together a knowledge of science and other important fields of interest.

The Science Teacher

One member of this team is the science teacher. He or she has a background in science and in education. His goal is to find new and better ways of helping students to understand science. Because he has a deep interest in science, he tries to arouse such an interest in his students, so that they may become interested in a science career. One of his tasks is to lead youngsters into science careers, for we will need many scientists.

Science teacher Bobby J. Woodruff watches as his students do an experiment. In his classroom, and after class in science clubs, Mr. Woodruff tries to interest young people in science.

Science editor Sidney Seltzer helped to develop the book you are reading. Here he talks with J. Darrell Barnard, one of the authors.

Science writer Earl Ubell reports on science for a large city newspaper. Here he gets firsthand information from scientists.

The Science Editor

A science editor has a background in science, in writing, and in the production of books and magazines. It is his job to bring together experts in many fields of science and education and work with them to develop science books and magazines. A science editor helped prepare the textbook you are reading. He talks with authors and develops outlines, reads the writing produced from these outlines, rewrites and writes material for the books and magazines, and works with artists, designers, and photographers. It is the science editor's job to keep up with the latest happenings in science as well as the latest methods for teaching science.

The Science Writer

A science writer combines a background in science and skill in writing to prepare articles about science for newspapers, magazines, and books. His job is to write about science in a way that people with limited education in science can understand. He travels to science meetings, science laboratories, and universities and meets with scientists to find out about new developments. He may write television and radio stories about events in science. He may write books on science topics for youngsters or adults. Look in your newspaper and in magazines for science articles. Then learn about a well-known science writer.

If you drew a large square on a deflated balloon, describe the shape it would have when the balloon was blown up. (Practice in forming mental images.) Let pupils test their hypotheses by performing the action.

If you placed two bathroom scales on top of each other and then stood on the upper one, how would the scales read? Justify your opinion. (Hypothesis formation.) Have pupils check their informed guesses.

Select skeleton pictures from outdated biology supply house catalogues. Have children justify their guesses as to the type of animal in each picture. Can they piece together enough information to justify their guesses? They should observe bone size and position, types of appendages, etc.

Devise a means of counting the number of grains of sand in a gallon jug. (Design of an information-finding technique.) Beach sand in a gallon jug has a count in the neighborhood of 100 million (10^8) grains. Suggest that direct counting of every grain is not wanted. A necessary hint that weighing a very small volume of counted grains could be one method.

NOTES:

Use this space for any additional teaching suggestions you may have.

George Solonovich illustrates many science books. He has an interest in science and in art.

Roman Vishniac is both a noted scientist and a well-known photographer.

The Science Illustrator

A science illustrator draws pictures and diagrams that help explain science principles. This textbook and other science books, magazines, and newspapers use this talent to show and explain things that photographs cannot. An ability to use pictures to explain things and an interest in both science and art are necessary to be a science illustrator. The picture above on the left shows a well known science illustrator at work.

The Science Photographer

When a record is needed of the way amebas reproduce, for example, a motion picture or a series of photographs may be made. Such work demands special techniques and a knowledge of the subject. Many times, the science photographer is both a scientist and a photographer. He uses his talents as a photographer and his knowledge of science to film scientific occurrences. The field of science photography will offer many opportunities in the future.

The Science Information Specialist

The five careers you have just read about provide science information. This information takes the form of books, newspaper articles, magazine stories, technical papers, films, filmstrips, records, and tape recordings. Every year millions of technical reports and thousands of books and audiovisual aids are produced. How can all these be stored so that they are available when needed by scientists, students, and other interested people?

This is the task of the science information specialist, who seeks better ways to store information and to locate such information quickly when it is needed. A knowledge of science and library work makes the information specialist an important person for the scientist seeking specialized information or for the student writing a paper on a famous scientist.

The team of people you just read about brings you the work of the scientist in words and pictures that you can understand. Their careers show how an interest in science and an interest in another subject can be combined. There will be many opportunities for careers in these fields. Every year, more and more teachers, editors, writers, illustrators, photographers, and information specialists are needed.

Science information specialists are trying to find new ways to store science information.

The Science Team in Action

Today science is a field of specialists. A biologist may specialize in virology, zoology, bacteriology, ecology, botany, or biochemistry, among many other areas. A physicist may specialize in nuclear physics, chemical physics, solid-state physics, geophysics, or biophysics, among other fields. The same degree of specialization is possible for engineers. Today's scientists find many ways to use their special interests and abilities. Curiosity leads them. And so it is not strange to find chemists, physicists, and biologists working on the same project.

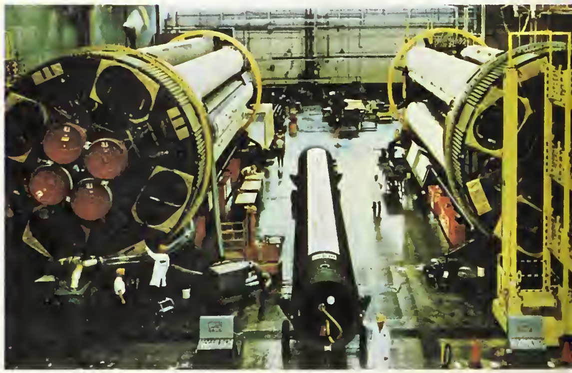
NOTES:

Use this space for any additional teaching suggestions you may have.

NOTES:

Use this space for any additional teaching suggestions you may have.

Thousands of men and women are needed to launch just one spacecraft into outer space. This means many people with many talents and skills must work together. Food must be prepared, models must be made, rockets must be manufactured, and experiments must be conducted. The work does not end with a launching. Each mission brings back information that must be studied. The results may be that new and better ways of doing certain things have been discovered, or that adjustments have to be made, or that it is necessary to start all over again because something did not work properly.



In June, 1965, six United States scientists—two medical doctors, one geologist, one physicist, one college teacher of electronics engineering, and one teacher of physics—were chosen to train for flights to the moon. Why do you think scientists are needed for future space flights?

If you visit a center for space research, you will find biologists studying the ways in which weightlessness affects the human body. Chemists will be found developing liquid foods. Physicists will be plotting the course and direction of a rocket and determining how long it will stay in orbit. Engineers will be found designing and building rockets. Meteorologists will be studying atmospheric conditions to determine the best time to fire the rocket. Science writers will be preparing stories for magazines and newspapers to inform their readers about what is happening. Science photographers will be taking pictures which will appear in magazines, newspapers, and movies and on television. Aerospace technicians will be busy fueling the rocket, checking its instruments, and manning tracking posts.

All these people have special jobs to do. Without each one's special knowledge and skill, the job of sending a rocket into space could not be done. This interdependence is found not only in space research but also in atomic energy research and cancer research, to name just a few areas.

Teamwork will play an important role in the science of today and tomorrow. But there will always be a place for those who wish to work alone.

Willard F. Libby, Nobel Prize winner in chemistry in 1960, once said, "We scientists are the only people who are not bored, the only adventurers of modern times, the real explorers—the fortunate ones." Scientists are today's real adventurers, but there is also much adventure ahead for those who keep up with science—today and tomorrow.

NOTES:

Use this space for any additional teaching suggestions you may have.

NOTES:

Use this space for any additional teaching suggestions you may have.

PLACES OF SCIENTIFIC INTEREST

There are many ways to learn about science. You can read the newspapers daily, and you can read books and magazines about science developments. You can watch special science television programs and listen to science radio programs. You can visit science museums and other places of scientific interest. On pages 386 and 387 you will find a list of such places. On these two pages you will get an idea of what you will find when you visit a museum or a zoo.

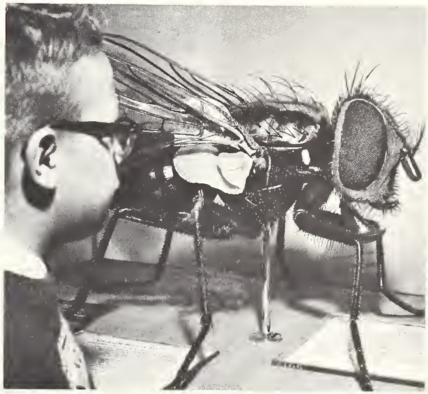
At the Smithsonian Institution, in Washington, D. C., visitors look at *Freedom VII*, the first United States manned spacecraft.

Visitors get a chance to look through a telescope at the Science Museum of the Franklin Institute in Philadelphia.

In 1964, the Hall of Science opened at the New York World's Fair. After 1965, it will be a permanent museum in New York City.

At the San Diego Zoo, visitors can walk through a rain forest and see the kinds of birds that live in such an environment.

Two boys watch a pendulum as it makes a sand pattern at the Boston Museum of Science and Industry. Other children pet a porcupine. One boy studies a giant model of a fly to learn its parts.



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Use this space for any additional teaching suggestions you may have.

NOTES:

Use this space for any additional teaching suggestions you may have.

Using What You Have Learned

Below you will find a list of books and booklets that will give you more information about careers in science.

1. *Scientific Careers in the Agricultural Research Service.* United States Department of Agriculture, Washington, D.C., Misc. Publication No. 798.

2. *Careers in Animal Biology.* American Society of Zoologists, Department of Biology, Goucher College, Baltimore, Md.

3. *Careers for Women in the Biological Sciences.* U.S. Dept. of Labor, Washington, D.C., Women's Bureau Bulletin 278, 1961.

4. *Careers in Biochemistry.* American Society of Biological Chemists, 9650 Wisconsin Ave., Washington, D.C., 20014.

5. *Careers in Botany.* The Botanical Society of America, Department of Botany, Univ. of Texas, Austin, Texas.

6. *How to Decide on Dentistry. New Dimensions in Dentistry.* Bureau of Public Information, American Dental Association, 222 E. Superior St., Chicago, Illinois.

7. *Your Career Opportunities in Medicine* and *Your Career Opportunities in Pharmacy.* Chas. Pfizer & Co., 235 E. 42 St., New York, N.Y., 10017.

8. *Microbiology in Your Future.* American Society for Microbiology, 19875 Mack Ave., Detroit, Michigan.

9. *New Careers in the Health Sciences.* National Health Council, 1790 Broadway, New York, N.Y., 10019.

10. *Careers in Science Teaching.* National Science Teachers Assn., NEA, Washington, D.C.

11. *What Is a Biologist? What Is a Medical Technologist? What Is a Pharmacist?* The Upjohn Co., Box 831, Kalamazoo, Michigan.

12. *Careers in X-ray Technology.* American Society of X-ray Technicians, 16 Fourteenth St., Fond du Lac, Wis.

13. *Careers Ahead in the Chemical Industry.* Manufacturing Chemists Association, 1825 Connecticut Ave., N.W., Washington, D.C., 20009.

14. *Careers in Mathematics.* National Council of Teachers of Mathematics, 1201 Sixteenth St., N.W., Washington, D.C., 20006.

15. *Careers in Atomic Energy.* U.S. AEC, Division of Technical Information Extension, Engineering and Education Section, P.O. Box 62, Oak Ridge, Tennessee.

16. *Physics as a Career.* American Institute of Physics, 335 E. 45 St., New York, N.Y., 10017.

17. *A Career in Astronomy.* American Astronomical Society, c/o J. A. Hynek, Dearborn Observatory, Northwestern University, Evanston, Illinois.

18. *Engineering, a Creative Profession.* Engineers' Council for Professional Development, 345 East 47 St., New York, N.Y., 10017.

19. *Industrial Engineers.* Occupational Brief No. 205, Science Research Associates, 259 E. Erie St., Chicago, Illinois. SRA Occupational Briefs are available in many other career areas.

20. *Careers for Women as Technicians.* U.S. Department of Labor, Washington, D.C., Women's Bureau Bulletin 282, 1961.

NOTES:

Use this space for any additional teaching suggestions you may have.

TEACHING SUGGESTIONS
(p. 384–385)

Background: These two pages constitute a review of the concepts and terminology introduced in this unit.

What You Have Learned: This is a summary of the entire unit, with new words in boldface type.

WHAT YOU KNOW ABOUT

Science–Today and Tomorrow

What You Have Learned

Of all the scientists who ever lived, 90 per cent are alive today. We live in an age of science, and it is important to be able to understand the world in which we live.

Bionics is a study of living things as systems. With the knowledge gained from such study, scientists and engineers try to copy these living systems and to join living and artificial systems.

The **biocell** is a source of electric energy that makes use of liquid fuels and microorganisms such as bacteria. The biocell obtains energy directly from living things instead of through fossil fuels or chemicals and changes this energy into electrical energy. Biocells are more efficient than other means of creating electric power.

Cryogenics is the study of temperatures near absolute zero: minus 459.7° F., or minus 273.2° C. At these low temperatures, metals become **superconductors.** They also repel magnetic fields. Some liquids become **superfluids** at these very low temperatures.

Lasers give off a very intense beam of light. This beam is very narrow and contains a tremendous concentration of energy. It is far brighter than the sun. This light can be used to bounce signals off objects in space, to carry messages, and so on.

Ultrasonics deals with ultra-high-frequency sounds—sounds that human beings cannot hear. Ultrasonic sounds act in a way similar to light beams. These sounds are used in sonar equipment and to clean materials, among other uses.

Today, science is a field of specialists. Each scientist and science technician contributes his special knowledge and skill to the job he does. There are and will be many opportunities for people to work in science.

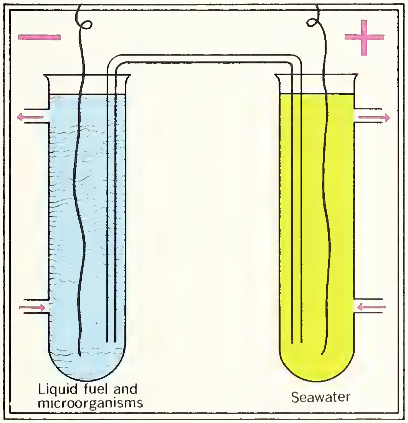
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

biocell	cryogenics	superconductivity
bionics	cryosurgery	superfluids
cryobiology	laser	ultrasonics

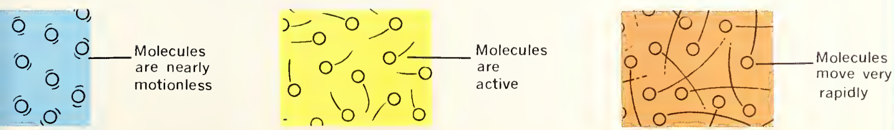
Complete the Diagram

Redraw this diagram in your notebook and fill in the parts needed to make this a biocell.



Can You Tell?

Look at the picture showing the activities of molecules in different metals, and tell for each picture whether the temperature of the metal is high, moderate, or superlow. Also tell whether or not electricity would flow well through the metals at these temperatures.



Checklist of Science Words: Remind the pupils that there is a *Dictionary of Science Words* on pages 390–393. They should consult this dictionary whenever they are unsure of the precise meaning of a word.

Can You Tell? The temperature of the blue drawing is lowest, that of the yellow drawing is moderate, and that of the orange drawing is highest.

Electricity flows very well through metals at superlow temperatures, flows well through certain metals at moderate temperatures, and does not flow easily or does not flow at all through metals at high temperatures.

NOTES:

Use this space for any additional teaching suggestions you may have.

YOU CAN LEARN MORE ABOUT

Science–Today and Tomorrow

You Can Visit

On these two pages is a list of places of scientific interest. If you do not find a place near your home, ask your teacher or write to your chamber of commerce to find a place near you.

Boston, Mass.
Museum of Science

New York, N.Y.
Museum of the City of New York
American Museum—Hayden Planetarium
American Museum of Natural History
New York Botanical Gardens
New York Zoological Park
New York Aquarium

Washington, D.C.
Smithsonian Institution
Museum of Natural History
United States Botanical Gardens
Naval Observatory
National Zoological Park
Planetarium, Rock Creek Nature Center
Kenilworth Aquatic Garden
National Arboretum

Philadelphia, Pa.
Franklin Institute
Franklin Institute Planetarium
Academy of Natural Sciences
Fairmount Park Zoological Gardens

Pittsburgh, Pa.
Carnegie Institute of Technology
Carnegie Museum of Science
Hall of Botany, Schenley Park

Chicago, Ill.
Adler Planetarium
Brookfield Zoo
Chicago Natural History Museum
Museum of Science and Industry
Lincoln Park Zoo
Shedd Aquarium
Morton Arboretum

St. Louis, Mo.
Missouri Botanical Garden
Forest Park Zoo
Forest Park Federal Fish Hatchery

Tulsa, Okla.
Municipal Rose Garden
Mohawk Park Zoo

Oklahoma City, Okla.
- Stovall Museum, U. of Oklahoma

San Antonio, Texas
- Brackenridge Park Reptile Garden
- Brackenridge Park Zoological Garden

Dallas, Texas
- Museum of Natural History
- Health Museum
- Aquarium
- Marsalis Park Zoo

Houston, Texas
- Hermann Park Zoo
- Hermann Park Museum of Natural History
- Hermann Park Botanical Gardens

San Francisco, Calif.
- Maritime Museum
- Golden Gate Park
  - Morrison Planetarium
  - Museum of Natural History
  - Steinhart Aquarium
  - Conservatory

Los Angeles, Calif.
- Los Angeles County Museum
- Griffith Park
  - Los Angeles Zoo
  - Planetarium and Observatory
- Palos Verdes Oceanarium
- Mt. Wilson Observatory, Pasadena

San Diego, Calif.
- Balboa Park
- Balboa Park Zoo

Denver, Colo.
- Colorado Museum of Natural History

Hawaii
- Bishop Museum, Honolulu
- Hawaii National Park

Alaska
- Alaska Historical Library and Museum, Juneau
- U. of Alaska Museum, Juneau
- Sheldon Jackson Museum, Sitka
- Mt. McKinley National Park

Philippines
- National Museum, Manila
- Institute of Science and Technology, Manila

Puerto Rico
- El Yunque National Rain Forest

England
- British Museum of Natural History, London
- South Kensington Science Museum, London
- British Museum, London
- London Zoo
- Kew Gardens, London

Montreal, Canada
- Maisonneuve Park Botanical Garden
- Redpath Museum, McGill University
- Montreal Botanical Gardens

Ottawa, Canada
- National Museum of Canada
- Arboretum and Ornamental Gardens, Central Experimental Farm

Toronto, Canada
- Royal Ontario Museum
- Riverdale Zoo

NOTES:

Use this space for any additional teaching suggestions you may have.

MATERIALS CHECKLIST

	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
Unit 1	yardstick cardboard scissors pencil a weight copper wire candle or alcohol lamp ruler pail narrow-necked quart jar graph paper heavy ball			

Do You Remember?

Green plants are living things that use the earth's materials to make food. Living things get energy from their food. This energy comes from the sun. Living things cannot create new energy; they can only change into other forms the energy that they get from the sun.

Green plants use energy from the sun to make a simple sugar called glucose. The process by which green plants capture and use the sun's energy is called photosynthesis. One product of photosynthesis is oxygen. All oxygen on earth is a result of photosynthesis. Thus all living things—all the animals as well as all the plants—depend on green plants for oxygen as well as for food.

Whenever living things die, their bodies decompose. The material, or matter, in the bodies of these dead plants and animals returns to the soil or to the water and is used again and again. Under ordinary conditions, matter can be changed, but matter cannot be destroyed.

Over millions of years, living things—plants and animals—become adapted to their constantly changing environments. Some animals, for example, *hibernate* during the winter. Other animals *migrate*, or move from places where it is cold in the winter to places where it is warmer. Some parts of the earth's environment have been changed very gradually during the periods of time known as the ice ages. At other times, some parts of the earth's environment were changed very rapidly by erupting volcanoes. The plants and the animals that survived such changes did so because they were adapted to the new environments that were created.

Living things are interdependent. This means that when the balance of nature changes, some living things may die unless a new balance can be reached between the size of their population and the size of their food supply.

Man also lives in nature. But often man does not replace enough of what he takes from nature. Often man does not look ahead. We have been using up our natural resources faster than we are replacing them. It is our responsibility to look toward the future and to plan so that tomorrow's world will have natural resources that are as plentiful as the natural resources that we have today.

Managing our resources and using them wisely is called *conservation*. We must conserve our fertile soil and find ways to use it to greater advantage. We must conserve our water, keep it clean and safe, and find ways to obtain more of it. We must manage our forests wisely and protect them from man's carelessness. We must find ways to remove the great amounts of industrial and other *pollutants* from the air. We must also prevent our wildlife from becoming *extinct*. Our human resources are our most important resource. We need to find many new ways to encourage and guide young people to build lives that are fulfilling and fruitful.

You can understand much about an animal by observing its behavior, which is the result of the animal's interactions with its environment. An animal's behavior depends in part on the information the animal receives through its *receptors*. Whatever stimulates a kind of behavior is called a releaser. Much can be learned about an animal's behavior by studying its *nervous system*, which *coordinates* the parts of the animal's body. As animals on earth became more complex, so did their nervous systems.

Scientific knowledge is increasing very rapidly. Modern science has helped man to change the way that he thinks about himself and about the world in which he lives. There are many new branches of science and many opportunities for anyone interested in science and science-related careers.

MATERIALS CHECKLIST

Unit 1 (cont.)	light ball croquet ball rubber ball
Unit 2	onion knife tablespoon homogenized milk medicine dropper glass slide cover slide microscope six 12-inch-long bars of different metals, each having the same diameter

MATERIALS CHECKLIST

	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
Unit 2 (cont.)	tin can metal-cutting tool nails wax bottle cloth bag that will loosely fit around the bottle kapok or cotton filler cardboard cylinder to hold the bag string			

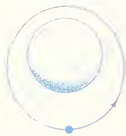
Dictionary of Science Words

acceleration (ak-sel-er-AY-shun). The rate of change in speed of a moving object. (p. 20)

accelerator (ak-SEL-er-ay-ter). A machine used by scientists to study the atom. (p. 112)

acclimatize (uh-KLY-muh-tyz). To become used to temperature conditions. (p. 317)

apogee (AP-uh-jee). The point on an orbit at which a satellite (like the moon) is farthest from the object being orbited. (p. 85)



atom. The smallest particle of matter that can be identified as an element. (p. 102)

balanced forces. The different forces acting on an object which cancel each other. (p. 65)

biocell. A battery of bacteria and a liquid fuel. Chemical energy produced by the bacteria is changed directly to electricity. (p. 352)

biochemist (by-oh-KEM-ist). A scientist who studies the chemical processes that take place in living things. (p. 240)

bionics. The study of living systems to find out what makes them work. (p. 349)

Canidae (KAN-uh-dee). The family of animals that includes wolves and dogs. (p. 330)

carbonic acid (kahr-BON-ik). A weak acid made of water and carbon dioxide. (p. 242)

Centigrade scale. A system of measuring temperatures in which the temperature of freezing water is zero degrees and the temperature of boiling water is 100 degrees. (p. 55)

central nervous system. That part of an animal's nervous system that consists of the brain and the spinal cord. (p. 325)

charge. An electrical charge is the quantity of electricity possessed by an object. (p. 110)

chemoreceptors (kem-oh-rih-SEP-terz). Those parts of an animal's nervous system that are stimulated by chemicals. (p. 308)

chlorophyll (KLOR-uh-fil). The chemical that enables plant cells to change carbon dioxide and water into sugar. (p. 239)

chloroplasts (KLOR-uh-plasts). Green-colored parts of plant cells. The chloroplasts make chlorophyll. (p. 240)

comet (KOM-it). A body, made up of rocks and gases, that orbits the sun. (p. 89)

conduction (kun-DUK-shun). The movement of heat or cold from one object to another of a different temperature. Also, the movement of electricity through a wire. (p. 50)

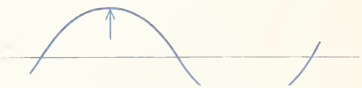
conductor. Any substance through which an electric current will flow easily. (p. 118)

conservation. Wise use of resources. (p. 267)

coordination. The ability of different parts of the body to work together. (p. 324)

corpuscles (KOR-puss-'lz). The name given by Newton to the particles that he believed carried light through space. (p. 194)

crest. The high point of a wave. (p. 221)



cryobiology. The study of living tissues that are at very low temperatures. (p. 359)

cryogenics (kry-oh-JEN-ikss). The science that deals with temperatures near absolute zero. (p. 355)

cryosurgery. Surgical operations in which supercooled instruments are used. (p. 359)

demagnetize. To remove magnetism. (p. 131)

diffraction (di-FRAK-shun). The bending of light as it passes a sharp edge. (p. 216)

diffusion. The process by which molecules move from an area where there are many to an area where there are fewer. For example, molecules of a drop of ink will diffuse in a cup of water. (p. 41)

electron. A particle that, while rotating on its own axis, is also revolving around the nucleus of an atom. (p. 103)

elementary charges. The charges of electricity that are carried by protons and electrons. (p. 111)

elementary particles. Particles of matter that cannot be further divided. These include protons, neutrons, and electrons. (p. 111)

ellipse (ih-LIPSS). An elongated circle. (p. 84)

English system of standard units. The system that is composed of such units of measurement as the inch, mile, pound, and degrees Fahrenheit. (p. 5)

epicycle (EP-uh-sy-k'l). The orbit of a satellite around a planet that is orbiting around the sun. The orbit of the moon is an epicycle. (p. 150)

epidermis (ep-uh-DER-miss). The covering tissue of a leaf. The outer layer of human skin is also called epidermis. (p. 238)

escape velocity. The velocity a rocket must reach to escape the pull of the earth's gravity. (p. 85)

ethologist (eh-THOL-uh-jist). A scientist who studies the behavior of animals. (p. 301)

extinct animals and plants. Complete families of animals and plants of which there are now no living members. (p. 277)

facets (FASS-its). The separate surfaces that make up an insect's eye. (p. 314)

Fahrenheit scale (FAR-un-hyt). A system of measuring temperatures in which the temperature of freezing water is 32 degrees and the temperature of boiling water is 212 degrees. (p. 55)

Felidae (FEE-luh-dee). The family of animals that includes lions, leopards, wildcats, and domestic cats. (p. 330)

First Law of Motion, *see* **Motion, First Law of.**

formula. A way of explaining ideas in a shorter form. Formulas often use symbols. (p. 14)

frictional forces (FRIK-shun-ul). Forces caused by objects that are rubbing against each other. Frictional forces cause moving objects to slow or stop. (p. 66)

galaxy. A large group of stars, such as the Milky Way. (p. 182)

galvanometer (gal-vuh-NOM-uh-ter). An instrument that detects electric currents in a wire. (p. 100)

gravitational mass. The property of an object that causes the object to be attracted by earth's gravity. (p. 106)

gravity. The force that attracts objects toward the earth's center. (p. 11)

hibernation (hy-ber-NAY-shun). The ability of some animals to sleep throughout the winter. (p. 256)

hypothalamus (hy-poh-THAL-uh-muss). The part of the brain that controls body temperature and appetite in mammals. (p. 326)

inertia (in-ER-shuh). The tendency of motionless objects to remain motionless and the tendency of objects that are in motion to continue moving in a straight line. (p. 106)

insulator. Any material through which electrons cannot easily flow. (p. 118)

laser (LAY-zer). An instrument that generates a very powerful beam of light called a laser beam. (p. 360)

lichens (LY-kunz). Crusty-looking plants that grow on rocks. (p. 242)

light-year. The distance light travels in one year. This distance is 6 million million miles. (p. 176)

MATERIALS CHECKLIST

Unit 3

strong metal ring
2 spring balances
wooden disk
cork
nail, to make hole in cork
balloon
yardstick
2 rubber balls
strong metal ring
4 pieces of strong rope
10 books of the same size
rubber band
roller skate
ink

MATERIALS CHECKLIST

	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
Unit 3 (cont.)	glass bottle and one-holed stopper teaspoon salt hot plate drinking glass salol test tube Wood's metal pan glass jar thermometer ball			

magnetic field. The space in which a magnetic force is present. (p. 127)

mass. The amount of matter in an object. It is the mass of any object that causes the object to be attracted by the earth's gravity and to have inertia. (p. 5)

matter. The material of which all objects are made. All matter occupies space and can be weighed. (p. 12)

mechanical receptors. Those parts of an animal's nervous system that are sensitive to pressure. (p. 319)

metric system of standard units. The system of measurement that uses the meter, the kilogram, and degrees Centigrade as standard units of measurement. (p. 5)

Miacidae (my-uh-SIH-dee). An extinct family of animals that lived 50 million years ago, ancestors of the cat and the dog. (p. 330)

migration (my-GRAY-shun). The instinctive seasonal movement of many animals and birds. (p. 256)

mosaic (moh-ZAY-ik) eyes. Eyes that consist of many separate lenses, each of which is separate from the others and transmits its own signals to the brain. (p. 314)

Motion, First Law of. If no outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed. (p. 69)

Motion, Second Law of. The rate at which an object changes its speed depends on two things: the mass of the object and the force applied to the object. (p. 77)

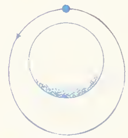
neutral atom. An atom that has the same number of protrons and electrons. This means it has exactly the same number of positive and negative electric charges which cancel each other out. (p. 112)

neutron. An elementary particle that is part of the nucleus of an atom. It has no electric charge and has almost the same mass as a protron. (p. 109)

parallax (PAR-uh-lakss). The apparent shift in position of an object when it is looked at from two different locations. (p. 159)

particle theory of light. The theory that light consists of very tiny particles of energy that travel in straight lines. The particle theory explains the fact that light can travel through empty space. (p. 194)

perigee (PEHR-uh-jee). The point on an orbit at which a satellite (like the moon) is nearest to the object being orbited. (p. 85)



photoelectric effect. The creation of an electric current when light strikes certain substances. Exposure meters used by photographers depend on the photoelectric effect for their operation. (p. 101)

photoreceptors. Those parts of an animal's nervous system that are sensitive to light. (p. 312)

pollutant. Any substance that poisons the air and causes harm to living things that breathe it. (p. 274)

polluted air. Air that is contaminated with chemicals and foreign substances. (p. 274)

predator (PRED-uh-ter). An animal that lives by hunting other animals. (p. 255)

protective coloration. The blending in color of an animal's fur or skin with its surroundings so that the animal is difficult to see. (p. 256)

proton. An elementary particle that is part of the nucleus of an atom. The proton has a positive charge of electricity. (p. 109)

protractor. An instrument marked off in degrees that is used to measure angles. (p. 164)

Ptolemaic (tol-uh-MAY-ik) model of the solar system. A model in which the earth is the center of the solar system, and all the other planets, the sun, and the stars revolve around it. (p. 148)

radiation (ray-dee-AY-shun). The giving off of heat, light, or other kinds of energy by the source of the energy. (p. 50)

refraction (rih-FRAK-shun). The bending of light when it enters a different substance. (p. 212)

retrograde motion (RET-ruh-grayd). The backward motion of an object that had been moving forward. (p. 150)

sea level. The level of the surface of the sea. The heights of all land surfaces are based on their distances above or below sea level. (p. 11)

Second Law of Motion, *see* **Motion, Second Law of.**

sensory equipment. The organs containing sensory receptors—chemoreceptors, photoreceptors, thermoreceptors, or mechanical receptors—with which animals receive information concerning the world about them. (p. 307)

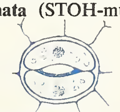
smog. A mixture of smoke and fog that pollutes the air, often causing harm to plants and animals. (p. 275)

social insects. Insects, such as bees, that live together in colonies. (p. 309)

sonar (SOH-nahr). An instrument used to measure distances under water. It does this by measuring the time it takes for a sound to be reflected back from distant objects. (p. 15)

standard units of measurement. Units of measurement that everyone agrees to use. (p. 5)

stomata (STOH-muh-tuh). Very small openings in the leaves of plants, through which carbon dioxide gas can enter. (p. 238)



superconductivity (soo-per-kon-duk-TIV-uh-tee). At very low temperatures, the ability of an electric current to flow through a conductor without any resistance at all. (p. 356)

superfluid. A liquid whose temperature is near absolute zero. Superfluids show unusual properties, such as "creep." Superfluids creep over the walls of their containers. (p. 358)

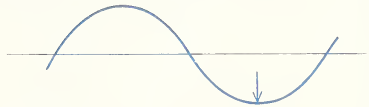
thermal (heat) **energy.** The energy produced by vibrating particles of matter. The vibration is caused by frequent collisions between free electrons and atoms in a conductor. (p. 123)

thermoreceptors. Those parts of an animal's nervous system that are sensitive to changes in temperature. (p. 316)

time interval (IN-ter-v'l). The space between two points of time. (p. 66)

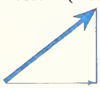
triangle. A closed figure with three straight sides and three angles. (p. 164)

trough (trawf). Low point of a wave. (p. 221)



ultrasonics. The science of sounds whose frequencies are above and below the range of human sensitivity. (p. 363)

vector (VEK-ter). An arrow representing a quantity that has both size and direction. A velocity vector indicates the speed and direction of a moving object. (p. 27)



velocity (vuh-LAHSS-uh-tee). The speed at which an object travels in a certain direction. (p. 26)

volume (VOL-yoom). The amount of space occupied by an object. (p. 11)

wave theory of light. The theory that light travels out in waves in all directions from its source. This behavior can be compared to that of the waves that form in the water when a pebble is thrown in a pond. (p. 217)

MATERIALS CHECKLIST

Unit 3 (cont.)

- metal ring large enough for ball to fit through
- ringstand
- Bunsen burner
- beaker of cold water
- 8-inch glass tubing
- flask
- wagon
- potato
- 2 forks
- pencil
- string
- bottle
- quarter

MATERIALS CHECKLIST

	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
Unit 4	brown wrapping paper scissors salt penny dime headphones compass coil of insulated wire bar magnet galvanometer copper wire iron wire			

Dictionary of Scientists

Bessel, Friedrich Wilhelm. A German astronomer who first measured the distance from the earth to a star. (pp. 24–25)

Carson, Rachel. The American biologist and author who wrote books about nature. She was interested in how pesticides and insecticides might change the balance of life. (pp. 264–265)

Copernicus, Nicolaus. A Polish astronomer who, in 1543, published the theory that the sun, not the earth, is at the center of the solar system, and that the planets revolve around the sun. (p. 153)

Frisch, Karl von. An Austrian zoologist who studies the habits of bees and how they communicate with each other. (pp. 320–321)

Grimaldi, Francesco Maria (grih-MAHL-dee). An Italian scientist who discovered that light bends when it passes through a very small hole. (p. 216)

Herschel, William (HER-shul). A British astronomer who discovered the planet Uranus. (p. 23)

Kelvin, Lord. A British physicist who, over a hundred years ago, stated that molecules of matter near a temperature of absolute zero have theoretically no movement. (p. 355)

Lavoisier, Antoine (an-TWAHN lah-vwah-zee-AY). The French chemist who discovered oxygen. (p. 21)

Leverrier, Urbain (er-BAN leh-vehr-ee-AY). A French astronomer who predicted the existence of the planet Neptune. (p. 23)

Lovell, Sir Alfred Charles Bernard. An English astronomer who studies the stars with radio telescopes. (pp. 180–181)

Maiman, Theodore H. American physicist who, in 1960, developed the laser. (p. 360)

Michelson, Albert Abraham. An American physicist who first measured the speed of light. He won the Nobel Prize in 1907. (pp. 198–199)

Newton, Sir Isaac. An English scientist who discovered the law of gravity, the laws of motion, how planets move, and that light is made up of many colors. (pp. 69, 86–87)

Onnes, Heike Kamerlingh. A Dutch physicist who, in 1913, won a Nobel Prize for producing the coldest temperature known to man —minus 272° C., or almost absolute zero. (p. 356)

Ptolemy, Claudius (TOL-uh-mee). A Greek astronomer who lived about 1800 years ago. He believed that the sun and the planets revolved around the earth. (p. 148)

Sisler, Frederick. An American scientist who, in 1962, developed a biocell that generated enough electricity to power a small radio transmitter. (p. 353)

Thompson, Benjamin (Count Rumford). An American-born scientist who lived in Europe. He discovered how heat behaves. (p. 46)

Thomson, Joseph John. An English physicist who discovered that atoms are made up of even smaller particles. (pp. 104–105)

Checklist of Science Activities

Here is a list of some things you can learn to do as you read this book. At the end of each unit there are four pages that tell you other things you can do.

MATERIALS CHECKLIST

Unit 4 (cont.)

candle
matches
silicon solar cell
selenium photovoltaic cell
milliammeter
flashlight or other bright beam
large iron washer
broken rubber band
sheet of colored paper
piece of aluminum foil
plastic or hard rubber comb
wire coil generator
bar magnet generator
other generators of electrical energy

MATERIALS CHECKLIST

MATERIALS CHECKLIST		QUANTITY	DATE NEEDED	SOURCE
Unit 4 (cont.)	pine shelving saw drill 2 small brass screws 2 paper clips (iron) fine-surface sandpaper pliers medium-sized sewing needle strong permanent bar magnet #70 cotton thread bell wire (enough to make a 6-inch-diameter coil of about 30 turns)			

MATERIALS CHECKLIST

Unit 4 (cont.)

cardboard
tape
dry cell
pencil
8" x 10" paper
nails and washers (iron)
galvanized washers or nails (copper, lead, zinc)
aluminum foil
tin-coated cans
other metals
salt water
vinegar
lemon juice

MATERIALS CHECKLIST

MATERIALS CHECKLIST		QUANTITY	DATE NEEDED	SOURCE
Unit 4 (cont.)	household bleach other liquids safe to handle 2 large sewing needles empty jelly jar waxed cork fur			
Unit 5	pencil yardstick chalkboard protractor long sheet of paper			

Index

MATERIALS CHECKLIST

Unit 5 (cont.)	penny, classroom clock, cardboard, tacks, flashlight, papier mâché, blueprint paper, cigar box, teaspoon, potassium dichromate
Unit 6	flashlight, book, watch

MATERIALS CHECKLIST

	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
Unit 6 (cont.)	bell			
	bell jar and air pump			
	large funnel			
	14 dominoes			
	40 marbles			
	large brick			
	carton			
	tape			
	aluminum foil			
	tissue-paper screen			
	black construction paper			
	ping-pong balls			

MATERIALS CHECKLIST

shallow box of gravel
mirror
long piece of string
jar of molasses
book
felt pad
smooth paper
pencil
checkerboard
cardboard
level table
several long wooden boards
carbon papers
penny

MATERIALS CHECKLIST

Unit	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
Unit 6 (cont.)	shallow bowl fluorescent light silk scarf 15-foot length of rope doorknob on door large-headed pin plastic tray unfrosted bulb cardboard box razor blade white paper 2 rulers			

MATERIALS CHECKLIST ✓

Unit 6 *(cont.)*

- transparent plastic container (20 x 10 x $1\frac{1}{2}$ inches)
- paper towels
- one-inch-thick wooden dowel
- board ($9\frac{3}{4}$ x 2 x $\frac{1}{2}$ inches)
- sheet of glass (10 x 3 inches)
- small pieces of cork or balsa wood
- basin
- 2 rectangular mirrors of equal size
- piece of cardboard (same size as mirrors)
- wax paper
- pane of glass
- 2 wooden blocks

	MATERIALS CHECKLIST	QUANTITY	DATE NEEDED	SOURCE
	small pieces of colored paper			
	clothespin			
Unit 7	radish seeds			
	pot of soil			
	magnifying glass			
	large jar or beaker			
	glass funnel			
	test tube			
	electric hot plate			
	kettle or pan			
	5 to 10 sprigs of fresh elodea plant			
	$1/3$ teaspoon baking soda			
	1 quart of water from an aquarium			
	cup of soil			
	sheet of paper			
	sheet of glass			
	microscope			
	aquarium			
	water plants			
	several small jars			
	dandelion plant			
	3-gallon bottle			
	pond water ($1\frac{1}{2}$ gallons)			
	soil (10 ounces)			
	elodea (5 sprigs)			
	guppy			
	snail			
	piece of clamshell			
	thermometer			
Unit 8	aquarium with fish			
	fish food			
	ant colony			
	glass jar			
	metal rail			
	sugar			
	table			
	vegetable dyes of different colors			
	boards			
	ladybugs			
	tree bark			
	smooth board			
	polaroid sunglasses or a polaroid filter			
	aluminum foil			
	lamp chimney			
	medium-sized flowerpot containing a growing plant			
	soil			
	cheesecloth			
	rubber band			
	goldfish			
	bowl			
	ice cubes			
	containers of pond water			
	elodea			
	electric light			
	thermometer			
	frog or toad eggs			

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MATERIALS CHECKLIST

boxes
aquarium tank
sand
small flowerpots containing plants
screen for top of aquarium tank
green chameleon
string
piece of meat or fruit
25-watt bulb
green cloth
brown cloth

NOTES:

Use this space for any additional teaching suggestions you may have.

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TEACHERS' GUIDE FOR *BOOK 6*

TEACHERS' GUIDE FOR *BOOK 6*

Science for Tomorrow's World

BARNARD
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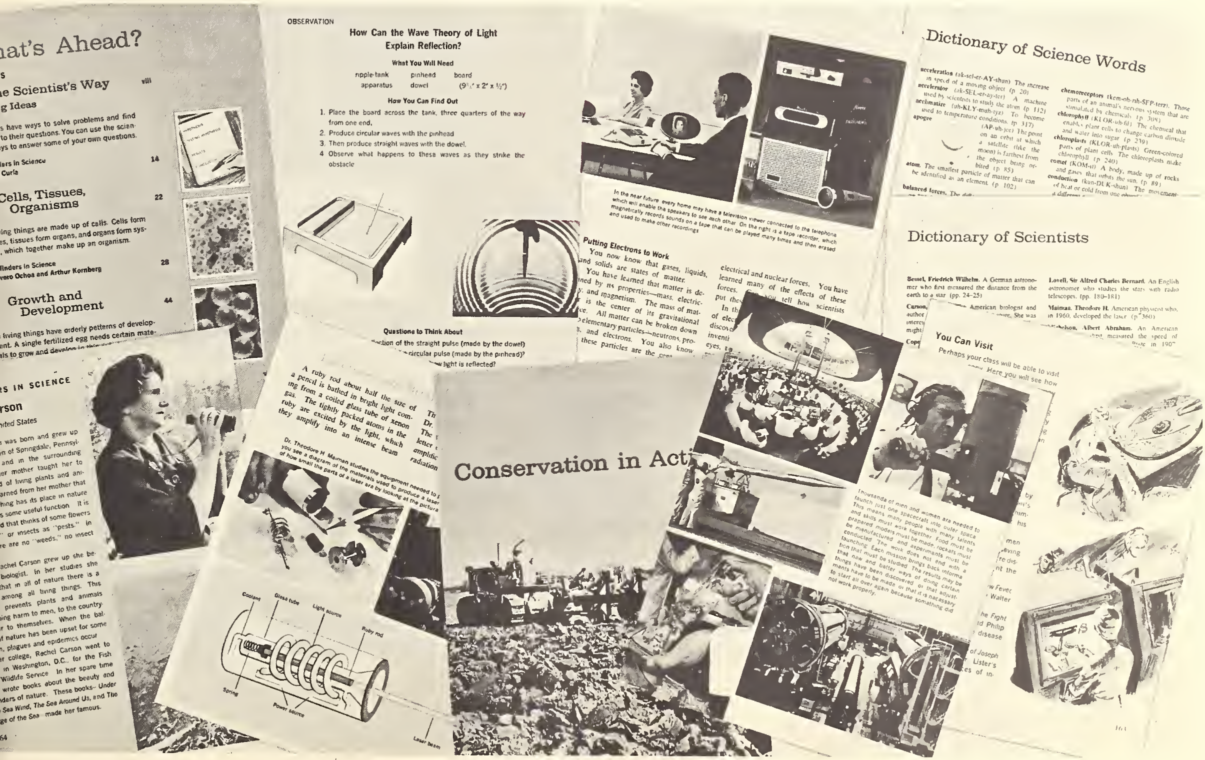
HERTZBERG

CONTENTS

Teachers' Guide for *Science for Tomorrow's World*

In most elementary schools, it is the classroom teacher rather than a specialist in science education who teaches science. Thus, the classroom teacher must have some knowledge of the subject matter of science as well as an awareness of how children learn. The Teachers' Guide of *Science for Tomorrow's World* provides help in both of these areas. We include supportive factual information to strengthen what the teacher already knows about science, as well as teaching suggestions based on the present knowledge of how children learn.

To be truly effective as a teacher of science, the teacher must have an understanding of what science *is* and what a scientist *does*. We often hear that the American child of today is growing up in a scientific age. What does this really mean? What exactly *is* sci-



ence? The answer to this last question will determine the teacher's approach and orientation to every lesson presented. To help the teacher gain a fuller understanding of the climate of our scientific age, we begin the Teachers' Guide with a discussion of the meaning of science and the work of the scientist.

SCIENCE AND THE SCIENTIST

Science is the study of natural phenomena; it concerns itself with describing such phenomena and attempting to explain them through laws that constantly can be tested and corrected against consequences in experience. These scientific laws are then fitted into a working model of the universe—a model that may be in the form of an idea, a diagram, or a construction (Book 6, p. 145). Often, scientists must do many experiments before a working model can be developed. Often, too, many experiments and much theorizing are done after the model is developed, in order to determine whether or not the model is accurate. An accurate working model may be highly useful in predicting future events. With a working model of the solar system, for example, it is possible to make predictions about when eclipses will occur, when Mars will be closest to the earth, when tides will be high, and where the earth will be in relation to other planets at any given time in the future. In some instances, a working model also helps to control man-made or natural phenomena. A model of motion that approximates natural motion is indispensable in controlling man-made motions such as those of a primitive oxcart or a modern space satellite. This is not to imply that science is concerned with prediction and control for practical reasons only. Such concern has grown out of man's need to dispel uncertainty, to know the world in which he lives.

In constructing a foundation for a model of reality, the scientist uses ideas of time, space, matter, causality, and number. In each of these areas, the scientist believes there is order; things do not happen in a haphazard fashion in the world of nature, but in a logical, noncontradictory manner. Thus, no matter what year, no matter what season, the sun always appears at dawn in the east. No matter what kind of projectile is launched from the earth into space, the projectile has two kinds of motion—a forward motion in the direction in which it was launched and a downward motion in the direction of the center of the earth.

From the dawn of history, man has sought to explain what he observed and then to use his explanations to predict future events. Even long ago, scientists believe, man was able to predict certain natural phenomena. They believe that an ancient people at Stonehenge, England, studied the movements of earth and sun and were able to place great rocks in such a fashion as to predict the beginning and ending of seasons and eclipses. We can find countless other examples to show that the order in the universe became evident to man's intelligence and that he used the test of prediction to prove the existence of that order. For example, at Stonehenge, it is believed that if ancient man's notions about movements of sun and earth were wrong, the sun would not have been seen rising over a particular stone on a particular day of the year; thus, the concept would have to have been changed accordingly. Sometimes when ancient man was unable to find an explanation for natural phenomena, he resorted to magic. Through magic, he thought himself able to explain a particular event, not by recourse to natural laws, but by the invention of uncontrollable "somethings" that he believed might yield to magical rites.

Why did man gradually give up magic and turn more and more to a search for natural laws? Psychologists find the explanation in the part of man's biological inheritance that is intelligence—a form of mental adaptation that causes man to seek to deal effectively with his environment. This basic need produces a tendency to give up explanations that do not conform to reality. Reality comes to be not what one perceives with the senses, but rather the product of trans-

formations that one performs upon data in the mind. A distant elm may appear to be smaller than a nearby birch sapling, but the mind puts each tree in proper spatial perspective. It may have seemed to ancient man that the sun traveled around the earth, but such a concept of the solar system is not consistent with all the known facts, and so man eventually constructed a more realistic concept of the solar system.

It is evident that science involves more than just the accumulation of new facts about the universe. Galileo's "facts" about motion are already known to anyone who has rolled an object down an inclined plane or thrown an object from a moving vehicle. All the facts needed to derive the concept of gravitation were known to man long before Newton. The great forward leaps in science have often come about not because man discovered new facts about the universe, but because a great scientific mind saw those same facts in a new framework. The search for new facts goes on continuously in scientific laboratories, but the major breakthroughs take place inside the minds of scientists themselves.

How do these breakthroughs occur? What does man look for to make the world more intelligible? Two guiding principles stand out: Man looks for *unity*, and he looks for *simplicity*.

To look for unity means to look for likenesses, often in unexpected places. It means, for example, seeing that the model of the solar system might also serve as a model for the atom. It means seeing similarities among the ant, the fish, the mouse, and man. For convenience, man may divide science into the study of the physical and the biological—the living and nonliving. But man searches for more than merely a similarity between any two related facts; he searches for a law that will explain *all* such related facts, and thus he strives toward unity.

The second guiding principle in man's striving to make the world more intelligible is that of simplicity. Man seeks the basic units—ultimate and fundamental units—out of which more complex matter is built. The discovery of the cell and the discovery of the atom were two milestones in man's striving toward simplicity. Present-day explorations of molecular activity in the cell lead further in the direction of unity and simplicity; eventually, the activities of all living things may be explained in terms of atoms.

In preparing *Science for Tomorrow's World,* the authors have been guided by a modern viewpoint of science. We have constantly asked ourselves what this modern viewpoint implies for science education in elementary schools. We turn now to a consideration of those implications which have guided our thinking in the planning and developing of this series.

A PHILOSOPHY OF SCIENCE EDUCATION

Three basic principles form the foundation of our approach to science education. First, we affirm our faith in the *natural curiosity of the child* as a *powerful motivating tool in acquiring science knowledge*. We believe that this curiosity can be kept at a high level, not necessarily by the use of bizarre or dramatic science activities, but by making explicit to the child the difference between his own view of reality and reality as it actually exists—as well as man can conceive of it. The child brings with him to the classroom a tremendous body of cognitive structures that he uses to explain the universe. The problem in teaching science to children is not that the child does not have explanations for natural phenomena; it is rather that his explanations are often either half-correct or wholly incorrect. Yet, if we can assume on the part of the child a basic urge to deal effectively with his environment, when he becomes aware of the discrepancy between what he believes and what is reality, we can then conclude that he will be more ready to apply the use of logic in his thinking. Here, both deductive and inductive (discovery) processes are invaluable. Some key concepts can best be taught by direct presentation that

is followed by applications of the key concepts to a wide variety of data. Thinking can be stimulated when the teacher says, for example, "How does what we have learned about sound apply to a mammal such as the bat? How can the bat's sense of hearing help the bat to know when an object is near?"

The discovery method is most effective when reserved for the induction of certain general laws. For example, in the study of animal behavior, children can discover for themselves some of the relationships between temperature and behavior. They can observe what happens to the behavior of a goldfish when the temperature of the water in the aquarium is lowered; they can note the movement of insects that have been placed in a box that is heated at one end. In the study of light, however, we cannot expect young pupils to use the inductive process to arrive successfully at the wave theory of light. Thus, deductive and inductive methods of presenting material have been used both selectively and realistically in *Science for Tomorrow's World* to achieve a maximum challenge to pupils' intellectual curiosity.

The second basic principle we accept is that *the elementary school child should gradually build a structure of science approximating the structure developed by the scientist.* Sometimes, in an effort to simplify subject matter, teachers have introduced erroneous concepts on the supposition that these concepts were easier for the child to understand. One such teacher taught that "Some insects lay eggs that hatch into worms"; he did this because he thought that "larvae" was too difficult a word to introduce to his second-grade class. It is possible, of course, to teach such a concept without actually using the word for the concept. But most important is that *the concept be accurate.* The biologist puts worms into a phylum that is completely separate from the phylum for insects; to say that larvae are "worms" puts a mistaken emphasis upon unimportant similarities in the appearances of the larvae and worms. We believe that a selection of simple but significant concepts can be taught so that even the young child has some exposure to the main ideas that structure a particular field of science. We also believe that children should know of man's long and continuing struggle to structure his knowledge—of the wrong turns he has made at times, and of how difficult it is to give up erroneous concepts even in the face of their inefficacy. Children should know and experience the exploration of the unknown, and they should also attempt to search for coherence in the world around them. Only then will they gain a perspective of science as man's attempt to decipher the code of the universe.

We have emphasized repeatedly man's basic tendency toward equilibrium—his need to resolve cognitive disturbance by accepting those ideas that fit with reality. But, as the history of science so dramatically illustrates, there is at the same time a strong tendency to resist change, to cling to cherished notions. In teaching science, we must not present a picture of the scientist as a kind of superman who readily accepts evidence that contradicts his own way of thinking. Part of the subject matter of science is the history of science; studying the history helps pupils to see the scientist as a human being, one who has had to engage actively in the process of accommodating to new theories—a process as difficult for him as for all other men.

The third principle we accept is that *the acquisition of knowledge can enhance logical thinking when proper attention is paid to processes.* The child becomes more logical in his thinking when he acts upon the data he assimilates, putting two and two together, making analogies by a one-to-one correspondence between parts, seeing the implications of one action upon another, setting up alternative hypotheses ("It's either this or that"), excluding variables that check out to be irrelevant. An important part of the teacher's responsibility in teaching science is to help the child acquire mental processes for transforming data so that

inconsistencies in thinking can be eliminated and reasoning can become more logical.

In teaching elementary school science, much has been made of the scientist's sequential method of searching for truth—of observing, hypothesizing, testing, noting results, drawing conclusions. Each of these activities is an important scientific activity, but note that the scientist does not necessarily proceed step by step from one activity to the next. Thus, observation is part of *every* scientific activity; or, a scientist in the process of testing may observe that a certain phenomenon does not conform to what he thinks ought to be happening, and as a result he may start off on a new and perhaps more important track. The elementary science curriculum ought to describe the scientist's methods. But in order to ferret out contradictions, in order to make children "think like a scientist," we need to emphasize (1) logical thinking, (2) the habit of testing concepts, and (3) the checking of concepts against their consequences in experience. To teach children a pat process is not the answer; we will return to this point later in our discussion.

The child, the structure, the processes—these are the foundation stones of *Science for Tomorrow's World*. While we deal with structure and processes in succeeding sections, there is no separate section on the child; consideration of the learner is woven into every section.

THE STRUCTURE OF SUBJECT MATTER IN THE ELEMENTARY SCIENCE CURRICULUM

In building a curriculum, the first obvious question that we ask is, "What is considered important for children to learn in the field of science?" With man's knowledge expanding at a fantastic rate, it becomes increasingly necessary to exercise great selectivity in choosing the subject matter that is to be taught to children. For the past ten years, scientists and teachers have been working cooperatively on this problem to produce new science materials for both elementary and secondary schools.

Let us look at an area commonly included in elementary science curricula—Living Things. The majority of pupils in elementary school study living things, but what are the pupils expected to learn? Past curricula taught generalizations such as, "There are many different kinds of animals," "Pets are our animal friends," "Earthworms help to make the soil good for the farmer," "The toad has a tough, dry skin," and "The toad uses its forked tongue to catch insect pests." The difficulty with such facts is that they do not *explain*; they do not help the pupil to grasp the underlying *structure* of the science of living things. Such facts about natural phenomena give descriptions in only a general and superficial way.

In contrast, the present trend in science teaching is to emphasize *key concepts* rather than specific facts. Specific facts are included, but they are seen in relationship to the key concepts. Granted that the toad has a tough, dry skin; the scientist then asks, "What does such a skin *do* for the toad?" In answering this question, the scientist draws upon the key concept of *adaptation*—adaptation being the adjustment that an organism can make to a given set of conditions because the organism possesses certain structures that have survival value and that are passed on to offspring. Such a concept explains many phenomena, from the dry skin of the toad to the claws of the lobster.

Next the scientist asks, "How does it work?" For example, "How is the forked tongue of the toad adapted to the particular diet of the toad?" "What enables the bat to hunt at night?" "How are the eyes of the bat adapted to night flying?" These questions lead to another key concept—the interdependence of structure and function. Again, as with adaptation, this key concept explains many phenomena: The tongue of the toad is uniquely built for "lightning-quick" action in catching and holding onto flying insects; the eyes of nocturnal animals have more rods than do

the eyes of other animals, and so the nocturnal animals are able to use the available light to see in very dark places.

The question of, "How does it work?" in relation to living things eventually brings the investigator to the cell, the basic unit of life. The key concept with which he works here is that the cell can be compared to a factory where raw materials are processed according to chemical instructions inherent in the genes of the cell. The cell's finished products are released into the bloodstream to find their way to the appropriate part of the organism.

From "How does it work?" the scientist goes on to ask, "How did it come about?" The answer to this last question lies in the evolutionary principle that individual differences in the offspring of an animal are passed on to succeeding generations if the differences have survival value. Over millions of years, these differences have led to the enormous diversity of living things in existence today. For example, pupils can trace from a common ancestor the gradual evolution of separate families of dogs and cats. Such an activity is more intellectually exciting than merely learning the fact that "The dog is man's friend."

In the physical sciences also we can find a contrast between the "old" science and the "new" science taught to elementary school children. Let us take, for example, the topic of motion. In many programs, a pupil learns, "A wagon goes faster downhill because of gravity; gravity pulls things toward the center of the earth." But to tell a pupil that gravity makes something accelerate on a decline is only to give a *name* for the phenomenon; it does not really *explain* the phenomenon. For an explanation of any motion, the scientist turns to Newton's three laws. The scientist can predict from one of them that a constant force applied in the direction of the motion will make the object accelerate. This key concept of the effect of a constant force can be used over and over again—to explain why a bicycle will accelerate even though the rider pedals with the same force or why an object falls faster as it nears the ground.

The scientist, using another of Newton's laws, can also predict that for any action in one direction there is an equal and opposite reaction. Again we find that this key concept can be used over and over. The frog is capable of a broad jump of several feet, but only by pushing backward against the mud or sand from which it springs. An inflated balloon released in the air will push forward rapidly as the air inside the balloon jets out, demonstrating the principle of movement of a jet airplane.

THE CONCEPTUAL FRAMEWORK OF "SCIENCE FOR TOMORROW'S WORLD"

From a study of what scientists themselves consider important in science, the authors of this series have identified key concepts to serve as the conceptual framework for an elementary science curriculum. It is interesting to note that these concepts are limited in number; in only ten statements, presented in the section that follows, we have been able to encompass the principal achievements of all of science. These key concepts are the backbone of the science curriculum developed in this series. Each of the concepts has been broken down into elements and the elements arranged from the simple to the more complex, so that the structure of a discipline is gradually acquired by pupils as they progress through the grades. Examples of such sequential development follow.

1 *Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.*

Throughout his study of science in elementary school, the child ought to come to grips with the ques-

tion of what science is all about and how the scientist proceeds to carry out his work. To many children, science merely means such things as satellites going off into space, mysterious brews bubbling over Bunsen burners, or tiny forms of life being viewed under microscopes. The children identify conspicuous activities of some scientists as being science itself, erroneously viewing the purpose of the scientist as essentially practical—to make life easier, safer, and more livable for man.

How can we convey a different picture? How can we help the child to acquire a concept of science as a search for order in the universe? Even the young child is aware of events in the natural environment. He is aware of change—day changing into night, leaves falling and new leaves appearing, grass turning brown and then green again, weather changing, living things changing with age. But what the child is not aware of is that events happen in an orderly rather than in a haphazard, or chaotic, way. The child who first enters school is inclined to explain events by anthropomorphism, attributing to natural phenomena either a human knowledge or a human-like will to make things happen. Thus, grass turns green "because it wants to and because green is prettier," and birds fly south "because they know that winter is coming." The problem for the teacher is to encourage and help children to view science as an attempt to explain natural phenomena, not in terms of anthropomorphism, but in terms of certain fundamental natural laws.

There are several ways to accomplish this objective. The content of science itself helps. The primary school pupil studies tornadoes not as chaotic events but as the result of changes in air conditions. He finds out that a seesaw is balanced not because "the seesaw wants to," but because the *forces* on each side of the seesaw are balanced. Scientific explanations for familiar phenomena help the child appreciate science.

Emphasizing the key concepts that make up the structure of science is another way to help children to view science as a search for order in the universe. For example, the child who from the first grade has been exposed to basic concepts about the motion of objects tends to develop a conception of science as a search for basic laws. Such a conception is radically different from the conception of the child who continually interprets events in the world of nature in terms of their meaning for man only. A science curriculum that emphasizes such concepts as that some animals are useful to man conveys a very different idea of science from that conveyed by a curriculum that says that no two offspring of an animal are alike; differences passed on from generation to generation tend to accumulate, so that over millions of years a tremendous variety of living things has evolved on the earth ("Life on the Earth," Book 6).

Exposing a pupil to the "scientist's science" is one way of widening the child's appreciation of science. Another way is to include a historical perspective of science. In *Science for Tomorrow's World,* for example, as children find out how man's ideas of the solar system have changed over the centuries, the children come to view science as a questing for better answers. One "Pathfinders in Science" section in Book 3 illustrates how the genius of one man, Copernicus, caused an unwieldy concept of what is happening in the world of nature to be replaced by a more lawful concept—one that fitted the facts and explained the solar system more simply.

Still another way of conveying to pupils that science is a search for laws that explain events in the natural environment is to expose the children to the methods of science. Beginning with Book 3 of this series, and in each succeeding book, there is an introductory unit that conveys to pupils what the scientist tries to do and how he goes about his work. The child sees the importance of observation at every point. From observations of similar situations, he, like the scientist, tries to extract a kernel of knowledge, a principle that has wide application. The kernel is a

hypothesis only, for as the child comes to realize, a scientific principle is tentative; it may or may not explain new observations, and so ultimately it may have to be discarded for a point of view that can deal more successfully with the phenomena to be understood. Over and over again, the pupil finds out how man has changed his viewpoint on many things—the nature of changes on the surface of the earth (Book 3), the movement of the planets in the solar system (Books 3 and 6), what light really is (Books 4 and 6), what all matter consists of (Books 4, 5, and 6), and how magnetism and electricity are related (Book 6).

2 *Lawful change is characteristic of events in the natural environment; although living things tend to produce living things like themselves, over millions of years the earth and living things on the earth have changed, and diversified forms of life have evolved.*

As we have pointed out, even the young child is conscious of changes in the natural environment, but he lacks, as did man for thousands of years, the historical perspective. The young child does not realize the cumulative effect of the small changes that he sees going on about him. Waters may muddy as they tear away at the banks of a brook or a creek, but the child does not see that a Grand Canyon is ultimately produced by such forces. He hears of a new breed of insect that is immune to DDT, but he does not see the same principle at work producing the tremendous variety of living things in existence today.

In this series, throughout each of the books, the child is exposed to the concept of orderly change. This concept of orderly change over an extended period of time begins in Book 2 with the account of the life cycle of the moth. In Book 3, the pupil is introduced to the notion of changes in living things and in the surface of the earth, while in later grades these changes are spelled out in considerably more detail. For example, in the unit entitled "How Animals Behave" (Book 6), the reader finds out how two separate families, dogs and cats, evolved gradually from a common ancestor.

3 *To find order in the natural environment, the scientist seeks basic units that can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.*

We begin the development of this concept by helping the young pupil to discover the fact that, like all other substances, air takes up space. In fact, the door of an "empty" car may be hard to close because of the pressure of air inside the car. The child can find out more about the "stuff" of which air is made by warming the air in a closed glass container and watching the beads of water collect on the cover. From such experiences he discovers that matter can exist in particles that are too small to be seen with the naked eye—particles such as the individual molecules of water in a cloud of water vapor or the individual cells that make up the pupil's body. Beginning in grade 4, he can use a magnifying glass to make some very small things visible and to examine actual cells or pictures of cells with a microscope. His knowledge of the structure of the cell is expanded, bit by bit, and the bits are related more fully in a separate unit on cells in Book 5. Similarly, readiness for the study of the atom is built throughout the grades, culminating in the chemistry unit in Book 5.

4 *All objects in the universe and all particles of matter are constantly in motion; man has discovered and stated the laws governing their motion.*

The study of the basic science of motion begins in Book 1. Here the pupil learns that things do not start to move by themselves: A push or pull, called a *force,* is necessary to make a thing move. As the pupil advances to Book 6, page 106, he will learn the formal

name for the principle introduced here—the principle of inertia—but for the first grade, the concept is developed without use of a formal name. The second grade pupil learns more about the laws of motion: Once an object is moving, it continues to move in the same direction and at the same speed, unless another force acts upon it; for example, a passenger in a car continues to move forward when the car stops suddenly, unless a force in the opposite direction is applied by an opposing object, such as a seat belt. In Book 2, he also discovers that a steady force on an object in motion will make the object speed up. In Book 5, the pupil delves into the discoveries of Newton and learns that an object shot off into space has two kinds of force acting on it—a forward force, causing the object to continue in the same path and at the same speed at which it started (a review of the concept taught in Book 2), and a downward force, resulting from the force of gravity (a review of a concept taught in Book 3). The effect of these two kinds of force working on the object is that the object follows a curved path, since the constant forward force of the object is continually being deflected by the constant force of gravity.

The motions of heavenly bodies and the laws governing those motions are also presented in step-by-step fashion. The primary grade pupil finds out how movements of the earth in relation to the sun cause daily and seasonal changes, while the intermediate grade child studies the differing theories of Ptolemy and Copernicus to better understand the motions in the solar system. The movement of stars as a navigational aid is explained in Book 8, and the meaning and use of time zones is included in Book 9.

Not only are the motions of the largest objects in the universe covered by this key concept, but so also are the motions of the smallest particles. In grade 4, the pupil is first introduced to the concept of molecules and their motion in moving air. The grade 5 pupil learns that the state of matter—solid, liquid, or gas—is determined by the motion of molecules, and the grade 6 pupil finds out about the rotations of electrons within the atom.

The study of motion is not confined to the physical sciences. As the pupil studies the circulation of blood (Books 3 and 5), the transportation systems of plants (Books 4 and 6), and the movement of materials in and out of cells (Books 3, 4, 5, and 6), he has the opportunity to apply physical principles (such as the concept of diffusion) to the functioning of living organisms.

5 *The motion of particles helps to explain such phenomena as heat, light, electricity, magnetism, and chemical change.*

To the elementary school pupil, it may seem unreal that the particles of matter in all objects are constantly in motion. It may be hard for him to think of his desk, for example, as being made up of moving particles. In his desk, as in any solid, the average position of the particles is fixed; they cannot move past one another, although they can vibrate. But if the pupil rubs his fist hard and fast over the surface of the desk, the spot warms up as the particles move more rapidly and farther apart. He can infer from certain experiences—the transfer of heat from warm things to cold things, the expansion of hot objects and the contraction of cold objects, the heating up of a wire carrying an electric current, the growing of a crystal in solution, the process of chemical change—that particles *do* exist and that they must be in motion to produce the phenomena he is observing. In fact, it is *only* as the pupil becomes aware of the motion of molecules that he can understand such phenomena as heat, light, electricity, magnetism, and chemical change.

Readiness for the concept of molecular activity begins in the primary grades. In Book 1, the child discovers that there is a relationship between temperature and rate of evaporation. In Book 2, the effect of heat upon volume of gases and liquids is introduced,

as is the relationship of heat to changes in state of matter from solid to liquid to gas. In Book 4, the pupil finds out about electron motion in current electricity, and in Books 5 and 6, he learns about the structure of the atom and the concept of the motion of particles applied explicitly to heat, light, electricity, magnetism, and chemical change.

6 *There is a basic tendency toward stability or equilibrium in the universe; thus, energy and matter may be transformed, but the sum total of matter and energy is conserved.*

Beginning with Book 2, pupils get their first exposure to one of the key concepts of science—conservation of matter. At this level, pupils discover that the matter (a ball of cookie dough) remains the same even though the matter may be transformed in appearance (made into cookies). In grade 3, in connection with a study of changes on the earth, pupils find out that while a river may cut deeper and deeper into its bed, carrying away soil in the process, the soil that is carried away does not dissolve into nothingness in the water. The soil may be transported and dropped at the river's mouth, but it is not lost. *The total amount of matter in the system at any point in the transformation remains the same.*

Similarly, the pupil learns that energy can be transformed. The primary child can understand that energy in the form of gasoline in the tank of a car must be transformed by burning if the car is to be able to move. In the same way, energy is produced in the body when food is burned during the digestive process. Furthermore, there is a relationship between the amount of energy available to do work and the intake of fuel or food. A car without gas will stop, and a hungry person soon becomes tired. Such commonplace, easily understood examples provide the basis for understanding the concept that although man may make transformations in a system, the equation for the system will balance at the end of the transformation.

7 *When equilibrium is upset in organism-environment interactions, regulatory mechanisms go to work to restore equilibrium.*

This key concept involves the basic tendency of organisms to strive for equilibrium. Temperature regulation is one of the best-known examples. In human beings, equilibrium with respect to body temperature exists at about 98.6° F. Evaporation of water from any surface has a cooling effect. When the body becomes overheated, we perspire, and equilibrium is restored; when the body is chilled, goose bumps on the skin reduce the exposure of blood vessels to the cold, and body heat is conserved. When equilibrium in body temperature is restored, the goose bumps subside.

From the simplest plants and animals to the most complex, we can find illustrations of how certain mechanisms go to work to restore equilibrium when it has been upset. These mechanisms serve the function of helping the organism to survive.

8 *There is a relationship between structure and function; the structure of parts of living organisms determines the function of those parts.*

In the development of this key concept, we use the same approach as for the other key concepts in *Science for Tomorrow's World*. We begin in the primary grades with examples of the relationship between structure and function. Even the first grade pupil can observe in real life or in pictures that not all birds can scoop up fish from the sea or dig for insects in the trunk of a tree. Observations lead to the concept that the beak structure of a bird enables the bird to obtain food in a special way—a concept that leads to further observation and discovery of more specifics. For the older pupil, the relationship is stated explicitly. First

the pupil is exposed to many examples: in the unit on "How Animals Behave" (Book 6), there is a detailed discussion of the sensory receptors of animals—from the planarian to the fish. The remarkable chemical receptors of the male fish not only enable it to detect male-female differences in other fish of the same species, but also to detect when the female is ready to mate. Even the simple planarian, as pupils can observe, uses chemical receptors on each side of its head to detect food, waving the receptors from side to side to find the greatest source of stimulation. Thus, the key concept is stated for the pupils: "The way in which sensory receptors are made (their structure) is related to how they work." The pupils are then asked to apply the concept to any independent observations they make of animals not discussed in the text.

9 *The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.*

That there is a relationship between mathematics and science is common knowledge. The student, however, should be encouraged to deal with the relationship well before he has to use calculus in high school physics; as is true for other key concepts in the basic structure of science, readiness should begin in the primary grades.

The first step in a pupil's appreciation of the relationship between mathematics and science is to have him quantify his data. This can begin in the first grade. A pupil learns that a seesaw is in equilibrium when the same number of books of equal size and weight are placed equidistant on both sides of the fulcrum. Through experience, he learns to coordinate weight and distance in a systematic way; a large weight at a small distance on one side balances a small weight at a large distance on the other side. Quantification of data extends to record keeping, and *record keeping involving two variables is encouraged.* In Book 2, for example, pupils learn to keep a record of the temperatures of jars of water that have been covered with materials of different colors. The children also learn to record the length of time that the jars are kept in the sun. Thus, both temperature *and* time are recorded. The important mathematical concept of *function*—that a change in one variable can result from a change in another—receives reinforcement here. Record keeping in the form of a double-entry table is encouraged. Use of such tables need not be postponed until the upper grades; even a pupil in the second grade can learn to read a double-entry table, as well as to classify certain objects in terms of size and weight:

		SIZE	
		Small	Large
WEIGHT	Light	||	|
	Heavy	|||	||

This chart, for example, shows that of the objects to be classified, two are small and light, one is large and light, three are small and heavy, and two are large and heavy.

Many experiences of this kind help the pupil to develop the mental agility needed to deal with concepts involving two variables. Thus, in *Science for Tomorrow's World, speed* is defined in terms of distance covered in a certain length of time; *density* is defined by the amount of matter contained in a given volume of space; *force* is defined by the relationship between mass and acceleration. The pupil who can see such concepts on a graph is clearly better equipped to deal with these concepts. He can think more understand-

ingly about them because his mind has been trained to think in this fashion during the period of his elementary school years.

Two units in particular in *Science for Tomorrow's World* are devoted to the relationship between mathematics and science. Book 5 contains a unit on "Testing Ideas," which introduces pupils to probability theory; an entire unit in Book 6 is devoted to developing the concepts of "a unit of measurement" and the "meaning and methods of measuring space, time, and matter."

10 *Man has changed and continues to change the natural environment; but because he is often ignorant of long-range consequences, his actions may have harmful effects for himself and for other living organisms.*

One of the basic problems facing modern man is that of maintaining a dynamic equilibrium with his environment. It is commonplace today to point out the rapid pace at which man is depleting elements of his environment. Water and air pollution, overpopulation, and improper use of chemicals are only a few of the many problems that man must solve if he is to function at an optimum level in the world of nature. Many such problems arise because man does not foresee the long-range consequences of his actions. For example, no one was able to predict that the wholesale use of DDT for the spraying of insects would result in the killing of many birds, or that the clam and oyster industries along parts of the Atlantic seaboard would be threatened by the dumping of wastes into coastal waters. Man must begin to develop foresight if he is to survive; he must become more concerned with the *total* natural environment.

There are moral and philosophical, as well as scientific, considerations involved in the above key concept about man and the natural environment, and obviously the elementary school child is not equipped to deal with them. But even a second grade pupil is capable of understanding that living things need air, water, food, and proper temperatures to survive. He can find out by experimentation what happens to plants deprived of one or more of these essentials of life. Third grade children can learn what is needed to make safe drinking water and, also, how man has contributed to water pollution. By the fifth and sixth grades, pupils are ready for a study in greater depth of some of the many other problems of man's own making ("Life on the Earth," Book 6). Of course, pupils cannot arrive at solutions to these problems, but the teacher can create a climate of opinion so that in later years, as adults, these same pupils will be more aware of both the necessity of managing natural resources with greater intelligence and the long and thorough pilot studies that are needed before any new products and solutions can receive full-scale application.

The ten key concepts that we have discussed form the structure of science in *The Macmillan Science Series*. Two things are worth emphasizing about these key concepts. The first is that all of the structure of science can be set forth in *so short a list;* the second is that there is considerable agreement among scientists that these ten key concepts actually *do structure science*. The reader may be interested in comparing the key concepts basic to *The Macmillan Science Series* with the set of propositions published by the National Science Teachers Association. These propositions are the result of extensive studies concerning the question of what to teach elementary school children. These studies were carried out by scientists and teachers working together. The following list, quoted from *Theory into Action*, published by the National Science Teachers Association, Washington, D.C., (1964) represents seven conceptual schemes and five major items in the process of science that were tentatively defined by the NSTA Committee as constituting the structure of science.

1. All matter is composed of units called fundamental particles; under certain conditions, these particles can be transformed into energy, and vice versa.

2. Matter exists in the form of units which can be classified into hierarchies of organizational levels.

3. The behavior of matter in the universe can be described on a statistical basis.

4. Units of matter interact. All ordinary interactions are either electromagnetic, gravitational, or nuclear forces.

5. All interacting units of matter tend toward equilibrium states in which the energy content . . . is at a minimum and the energy distribution . . . is most random. In the process of attaining equilibrium, energy transformations or matter transformations or matter-energy transformations occur. Nevertheless, the sum of energy and matter in the universe remains constant.

6. One of the forms of energy is the motion of units of matter. Such motion is responsible for heat and temperature and for the states of matter: solid, liquid, and gas.

7. All matter exists in time and space, and, since interactions occur among its units, matter is subject in some degree to changes with time. Such changes may occur at various rates and in various patterns.

The following are the five major items identified as essential to the process of science:

1. Science proceeds on the assumption, based on centuries of experience, that the universe is not capricious.

2. Scientific knowledge is based on observations of samples of matter that are accessible to public investigation in contrast to purely private inspection.

3. Science proceeds in piecemeal manner, even though it also aims at achieving a systematic and comprehensive understanding of various sectors or aspects of nature.

4. Science is not, and will probably never be, a finished enterprise, and there remains very much more to be discovered about how things in the universe behave and how they are interrelated.

5. Measurement is an important feature of most branches of modern science because the formulation as well as the establishment of laws is facilitated through the development of quantitative distinctions.

SEQUENCE IN THE SCIENCE CURRICULUM

The task of curriculum building in science includes a number of steps, the first of which is the identification of the key concepts that together add up to an understanding of the meaning of science. These key concepts have already been discussed. We have included in *Science for Tomorrow's World*, at the various grade levels, illustrations of these key concepts so that the children may see them materialized in learning situations. However, it is also essential that each key concept systematically be broken down into smaller pieces of relevant information. These smaller pieces must be arranged in sequential order from simple to the more complex, and the pieces must be assigned to proper grade levels.

A well-constructed development of concepts, taught in "spiral fashion" throughout the elementary school years (reinforcing every other year or two what has been learned earlier, and then advancing to a higher level of understanding) is essential for a meaningful understanding of science. The charts on the next two pages illustrate the sequence that has been developed in *Science for Tomorrow's World*.

1 Events in the natural environment happen in an orderly rather than a haphazard way; man searches for laws to explain this order by observing, hypothesizing, checking his ideas, and rejecting those which do not square with reality.

2 Lawful change is characteristic of events in the natural environment; although living things tend to produce living things like themselves, over millions of years the earth and living things on the earth have changed, and diversified forms of life have evolved.

3 To find order in the natural environment, the scientist seeks basic units that can be put together in an almost infinite variety of ways; the cell and the atom are examples of such units.

4 All objects in the universe and all particles of matter are constantly in motion; man has discovered and stated the laws governing their motion.

5 The motion of particles helps to explain such phenomena as heat, light, electricity, magnetism, and chemical change.

BOOKS IN WHICH KEY CONCEPTS ARE DEVELOPED AND THE NUMBER OF UNITS IN EACH BOOK DEALING WITH THE CONCEPT

KEY CONCEPTS	*BOOKS*						*TOTAL UNITS*
	1 (6)*	2 (6)	3 (6)	4 (9)	5 (9)	6 (9)	
1	6	6	6	9	9	9	45
2	1	3	1	1	1	2	9
3	0	1	1	2	3	5	12
4	1	3	1	1	3	3	12
5	3	3	0	1	2	3	12
6	2	3	1	5	4	3	18
7	1	3	1	1	2	2	10
8	3	2	1	2	3	2	13
9	1	2	0	2	4	7	16
10	0	0	1	0	1	1	3
Total Concepts	8	9	8	9	10	10	

** Number of units in the book*

6 There is a basic tendency toward stability or equilibrium in the universe; thus, energy and matter may be transformed, but the sum total of matter and energy is conserved.

7 When equilibrium is upset in organism-environment interactions, regulatory mechanisms go to work to restore equilibrium.

8 There is a relationship between structure and function; the structure of parts of living organisms determines the function of those parts.

9 The scientist has developed measures of space, time, and matter so that he can communicate explanations that are reproducible and make predictions about events in the natural environment.

10 Man has changed and continues to change the natural environment; but because he is often ignorant of long-range consequences, his actions may have harmful effects for himself and for other living organisms.

UNITS IN WHICH KEY CONCEPTS ARE INTRODUCED IN BOOK 6

KEY CONCEPTS	*UNITS*									*TOTAL UNITS*
	1	2	3	4	5	6	7	8	9	
1	X	X	X	X	X	X	X	X	X	9
2							X	X		2
3		X		X		X	X	X		5
4		X	X		X					3
5		X		X			X			3
6				X		X	X			3
7							X	X		2
8							X	X		2
9	X	X	X	X	X	X			X	7
10							X			1
Total Concepts	2	5	3	5	3	4	8	5	2	

TEACHING UNITS

Once major generalizations have been identified and the flow of ideas from grade to grade is roughed out, it then becomes necessary to plan teaching units suitable to the developmental level of the child. Each unit covers a period of instruction varying in length from two to four weeks. Such an arrangement of text material in eight or nine major blocks of subject matter permits more efficient teaching and learning than when a text is divided into thirty chapters with a different topic for each chapter. Under the unit arrangement the teacher does not shift gears every few days, having to gather equipment with each shift as well as having to reorient pupils' thinking.

The Table of Contents, which lists the titles of each unit of the first six books, is reproduced in Part IV. By looking at the titles, a teacher can tell at a glance whether or not the pupils have had any previous exposure to a particular area. The sequence charts on page 20 will reveal the amount and quality of the exposure.

An examination of the titles reveals some immediately familiar areas in science education. Such topics as "Probing the Atmosphere," "Living Things—Green Plants," "Light and Sight," and "Using Electricity" have been part of the elementary science curriculum for many years; although, as has already been pointed out, the specifics taught under each topic have often been different. In studying about light, for example, the children do not learn only that light is made up of particles traveling in a straight line; the children also learn that light particles travel in a wave motion, similar to the motion of a water wave when a pebble is dropped into a pond. Elements of key concepts are built into the topics, so that, although the topic itself is not new to the curriculum, each element becomes a vehicle for teaching the structure of science from a contemporary point of view.

Some topics reveal new developments in the sciences. Conservation of water resources and problems of air pollution are being emphasized today as much as conservation of soil was emphasized a few decades ago. This trend is reflected in the unit "Life on the Earth" (Book 6). Oceanography, for another example, is a rapidly expanding field of knowledge. With so many basic scientific data now known about life in the sea, ocean currents, salinity, and the geology of the ocean floor, the study of oceanography well deserves a place in the elementary science curriculum. The picture story "Probing the Oceans" (Book 5) highlights the work of oceanographers at the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, and will stimulate interest in this exciting field. Similarly, the stepped-up pace of man's exploration of space leads not only to the inclusion of space travel, but also to an increased emphasis on the science of astronomy.

PART II: HOW CHILDREN ACQUIRE SCIENCE KNOWLEDGE: A DEVELOPMENTAL APPROACH

For any discussion of how children acquire science knowledge, educators today lean heavily on the work of Jean Piaget, a Swiss psychologist who has been working with his collaborators in Geneva for over 40 years on the study of cognitive processes. Cognitive processes are those intellective processes by which knowledge is acquired. Piaget has developed a theory of how these processes begin in infancy and how they change as the child matures. His theory is a developmental one; characteristics of children's thinking are described in age-related stages. On the basis of Piaget's theory, we can predict the thought processes of children within a certain age range. There are, of course, individual differences in maturity of thinking; some children, because of heredity and experience, are more advanced than others; but, according to Piaget, the thinking of all children tends to go through the same stages and, on the average, when they are at the same age.

Piaget's description of developmental stages in children's thinking has generated a tremendous amount of research on both sides of the Atlantic. Many investigators have worked on the problem of whether or not his theory is a valid one. The conclusion to date is affirmative; the same stages characterize the thinking of Swiss, Norwegian, English, French, Canadian, and American children. In fact, when the tests developed by Piaget and his chief collaborator, Barbel Inhelder, are given to subjects in different countries, investigators report that translations show almost identical wording in children's answers. American cognitive psychologists, like Jerome Bruner of Harvard University, have extended and refined Piaget's theory, so that today we have a well-constructed and validated model of the thinking processes involved in the acquisition of knowledge. An understanding of how children acquire knowledge is basic to improvement of the teaching-learning process; we cannot help children to become better thinkers unless we know something about thinking processes and how they change with age, nor can we construct effective textbooks without taking into account developmental changes in cognition.

How can we put the findings of Piaget and other cognitive psychologists to work in teaching science? As we have pointed out, one of the aims of science educators is to teach the methods of science, to teach the child to use the same logical processes of thinking that a scientist uses to solve problems. For too long,

teaching the methods of science has meant teaching children to follow a formula: Observe; Hypothesize; Test; Evaluate. The formula is still valid, but it is not enough. The child in primary grades *does* observe, but, as we know from Piaget's work, he is likely to focus on the wrong property of an object or event as he observes. Similarly, the pupil in intermediate grades *does* hypothesize, but if he picks out the wrong variable for testing, he doesn't know what to do next. Nor does he know what to do next if he gets positive results from testing, for he doesn't know the specifics of "Evaluate"; he doesn't know, for example, that he must test for *exclusion* of other variables.

In developing *Science for Tomorrow's World* we set as goals that the texts should not only help the child build a structure of science (the scientist's science), but should also develop logical thought processes. We believe that the study of science can help children become better thinkers, but that there must be deliberate planning to achieve this end; the improvement of thinking processes should not be left to chance. Guided by the discoveries of Piaget and other cognitive psychologists, we have used content, activities, and illustrations in the series to foster logical thinking. We will now discuss what is known about the normal course of intellective development, before discussing how that knowledge can be put to use in teaching science.

For Piaget the development of intelligence begins as early as the cradle stage and continues through stages from birth to maturity. The first stage Piaget calls the sensorimotor. The infant comes into the world with two kinds of reflexes: those, such as the knee-jerk, that are not altered by experience, and others, such as grasping and sucking, that are modified as the infant exercises them. The modification occurs through assimilation and accommodation. The infant, for example, accommodates the grasping reflex to the shape of the object to be grasped, curving his fingers one way to grasp a long narrow object, and in a different way to grasp a ring. During the first 18 months, the infant carries on countless transactions involving space, time, matter, and causality which build and reshape developing mental structures. Witness what happens with respect to the notion of permanence of object. To the 2-month-old infant, the game of peek-a-boo is meaningless; for him an object ceases to exist when it disappears from view, and out-of-sight is out-of-mind. Later in the first year of life, the infant knows that an object continues to exist and delights in searching for it when it is hidden. He "knows," not in words, but in his sensorimotor system, in much the same way that we may "know" how to find our way through a still strange building the second time. For Piaget, sensorimotor intelligence is the intelligence of action. The infant must first carry out displacements in his *actions,* rather than in thought. If an object is hidden first in one place and then another while the toddler looks on, he must carry on a physical search for that object, going from cushion to cushion; he cannot sit back and point triumphantly to where the object is, for he cannot visualize its displacement in his mind. However, by 18 months the child is capable of representation, of imagining the environment other than as he directly perceives it.

The next stage, the *preoperational,* extends from 18 months, roughly, to about 7 years. It is in this stage that we find most first and second grade children—and, of course, some children even older than 7 years. This stage is called "preoperational" because the child does not use logical operations in his thinking. We can summarize the characteristics of pupils' thinking at this level as follows:

1. *The child is perceptually oriented; he makes judgments in terms of how things look to him.* When given a problem in which two lines of ten segmented sticks of equal length are laid out in parallel rows, he will see that both lines are equal. He will see that two dolls, walking along these paths, would each walk the

same total distance. But if one of the rows is rearranged in a zig-zag fashion, when the child is again asked if each doll takes as long a walk as the other, the child says, "No." Even when he counts the segments, he denies equality; the child does not see that there is a logical necessity in which ten must equal ten. Piaget has shown that this same type of perceptual judgment enters into the preoperational child's thinking about space, time, number, and causality. It is only as the child goes beyond his perceptions to perform displacements upon the data in his mind (for example, visualizing the second row of sticks straightened out again) that conservation appears.

2. *The child centers on one variable only, usually the variable that stands out visually; he lacks the ability to coordinate variables.* For example, a kindergarten child is pouring juice into paper cups. The standard-size cups run out, and the teacher substitutes some that are much higher but are also smaller in diameter. As the children drink their juice, several comment on the fact that Jimmy, Eddie, and Danny have more juice. Why? Because those children have cups that are taller. The dimension of height, not width, stands out. The child's thinking is rigid; he does not perform operations on what he sees. Later he will reason that "higher than" is compensated for by "skinnier than," and that both kinds of cups may hold the same amount of juice. This ability to see reciprocal changes in two sets of data is an important logical tool available to older children but not to the preoperational child.

3. *The child has difficulty in realizing that an object can possess more than one property, and that multiple classifications are possible.* It is hard for the child to see that one can live in Los Angeles and in California at the same time, that a bird is also an animal, and that, since there are animals other than birds, there are logically *more* animals in the world than there are birds. The operation of combining elements to form a whole and then seeing a part in relation to the whole has not as yet developed, and so hierarchical relationships cannot be mastered.

So far, this consideration of preoperational thinking has been largely negative. We have seen that the child lacks the ability to combine parts into a whole, to put parts together in different ways, and to reverse processes. What, then, can the child do? The development of logical processes is not at a standstill during this period; there are some positive accomplishments. We see, for example, the rudiments of classification: the child can make collections of things on the basis of some criterion; he can also shift that criterion. Thus if we present a kindergarten child with a collection of pink and blue squares and circles, some large and some small, and ask him to sort them into two piles with those in each pile being alike in some way, he can usually make two different collections on the bases of color and shape (a few children discover the third criterion of size). Such an ability, of course, is essential to the formation of classes and eventually of a hierarchy of classes.

The child is also beginning to arrange things in a series. He can compare two members of a set when they are in a consecutive order; he knows that Tuesday comes after Monday. But since Friday comes after Tuesday, which is after Monday, does Friday also come after Monday? This operation, involving seeing logical relations between things or events that are arranged in a series, is not yet possible to the preoperational child, but experiences with seriation are preparatory to the development of such operations. The "inching up" that an older pupil does in trying to establish equilibrium between two parts of a physical system (add a little to one side; then add a little to the other) is an example of a more sophisticated use of seriation.

Between 7 and 11 years of age on the average,

as the child assimilates information from his actions and accommodates mental structures to the new information, thinking processes change. The child abandons his perceptual judgments and thought takes on certain logical properties. Piaget calls this stage the stage of *concrete operations,* because, while the child uses logical operations, the content of his thinking is concrete rather than abstract. One of the mental operations that develops is that of combining elements; the child begins to put two and two together figuratively as well as literally. He uses this combining operation to discover (though not until toward the end of this stage) that a substance like sugar added to water will make the water level rise, and that the water level will stay up even after the sugar dissolves. It dawns on the pupil that matter combined with matter produces more matter, that matter doesn't disappear into nothingness.

Another property of logical thought is that elements of a whole can be associated in various ways without changing the total. Thus, in the problem of the segmented sticks, the segments can be "associated" in a straight line or zig-zag line, but the total distance of the path to be covered remains the same, or is conserved. And in studying science, the pupil can use the associative operation to discover how to keep a system in equilibrium—how, for example, when a muscle is flexed, it becomes shorter but thicker; when relaxed, it is longer but thinner. In each case, the total amount of muscle remains the same; the amount of matter is conserved, though its shape is changed.

A third property of logical thought is that of identity. The identity operation is basically a null operation; the child can mentally cancel out the effects of any operation by combining it with its opposite. He uses such an identity operation to reason that the effects of adding a force to one side of a balanced tug-of-war can be canceled out by adding a force to the other side (at the preoperational stage, he could solve the problem only by taking away the extra force that had been added). The pupil can also reason, as he thinks about a flexed muscle, that, since nothing has been added to the muscle and nothing has been taken away, then quantity of matter is identical before and after the flexing. An extension of the identity operation is the one-to-one correspondence a pupil carries on to establish identity between two sets. Is the spider an insect? The pupil must compare each characteristic in the set of insect characteristics with each in the spider set, on a one-to-one basis, to answer the question.

Of all of the properties of logical thinking, one of the most critical to develop is that of reversibility. Every change that the mind makes upon sensory data is reversible. The child can mentally rearrange the sticks in the zig-zag line, putting them back the way they were, to see that length is conserved. Similarly, a pupil can solve the problem of whether matter in a total system is conserved when a river carries away soil and deposits it in the river delta by reversing the depositing process. (See Book 3, Unit 3.)

A good deal of the research of Piaget and Inhelder on how children think about problems has centered on conservation problems in which matter, weight, or volume is conserved with a change in form. Results show that children achieve conservation during the stage of concrete operations, but that some conservation problems are easier than others. Conservation of length (the segmented sticks) appears first, followed in turn by conservation of matter (pouring sand into containers of different shapes) and conservation of weight. Conservation of volume (dissolution of sugar in water) is most difficult, appearing at about 11 years.

The operations described above characterize the thought processes of the child during the elementary school years, but beginning at about 12 years, there are further changes that occur in modes of thinking. Thinking is less tied to the concrete and becomes more abstract and formal. Piaget describes it as *proposi-*

tional thinking. The pupil can state propositions in terms of the variables he has identified and can then systematically combine the propositions so as to test all possible combinations. To reveal thinking processes, a pupil is presented in one of Piaget's tests with four flasks containing colorless, odorless liquids that look exactly the same, plus a bottle containing potassium iodide (not identified for him). He is shown that a few drops from the bottle can turn the proper (but unknown to him) mixture of liquids yellow, and he is asked to reproduce the process. If the pupil is at the formal stage of thought, his statements will reveal certain characteristics of thinking not found in younger children. For example, he will say, "If this stuff in the bottle is plain water, then when I put it with a mixture from the first and second flasks, it shouldn't make them turn yellow." In effect he is stating a hypothesis for testing, "If it's water, it wouldn't do this," or that one statement logically implies another. At the concrete stage, the pupil says, "I'll put this and this together and see what happens."

There are four ways in which propositions can be combined. We can combine by conjunction, as when we say, "It's got to be this *and* this"; by disjunction: "It's got to be this or this"; by negation: "It's neither this nor this"; and by implication: "If it's this, then this will be true." Let's suppose, for example, that a sixth grade child is interested in the problem of what attracts certain insects to flowers; two possibilities are design and color. How to combine the two? At the formal stage of thinking, the learner can systematically test all the possibilities by asking:

Is it color and not design?
If it's not color, then is it design?
Is it design and color?
Is it neither?

Each of these questions must next be stated as a hypothesis for testing. The question, "Is it color and not design?" must be restated as the hypothesis, "If it's color and not design, then when we present both stimuli (which are specified) to the insect, we ought to attract more insects to the color." But following the checking out of that hypothesis, if color "works," the pupil must then ask, "If it's color, is it any color? Does yellow work as well as red? Do fluorescent colors work better than nonfluorescent? If color red is equal to color yellow, the number of insects attracted to the stimuli should be the same." The outstanding characteristic of thought at the formal stage is the way in which the mind can combine propositions, going back and forth with lightning-like speed, and then stating what the combination implies in the way of experimental outcome. This mode of thinking begins to appear in bright children even before they leave elementary school.

BUILDING A SCIENCE SERIES TO FOSTER LOGICAL THINKING

The developmental picture we have described has implications for building a science series to foster logical thinking, as we shall see. However, it should be pointed out here that cognitive psychologists have made contributions other than the developmental picture. Piaget and Inhelder have given us insight into the misconceptions about science that children acquire, so that we can plan remedial activities. Bruner has described the process of concept building, a process that begins with a sensorimotor experience, proceeds to a step where a mental image is important, and then is completed at the symbolic level, where verbal understanding is accomplished. Aspects of cognitive theory other than the developmental picture have been considered in building our science series.

Implications of Cognitive Theory for Content Selection and Grade Placement

In building a science series, there must be a rationale for the selection and grade placement of sub-

ject matter. Part of the rationale is derived from scientists' analysis of what is important in science; we have selected for the content in this series the "scientist's science," ordered in terms of difficulty of concepts. Part of the rationale is derived, also, from what we know about the child. If the study of science is to improve thinking processes as the pupil acquires content, strategy for improvement must be based on what is known of the normal course of intellective development. In our discussion thus far, we have described the *normal course,* not the potential; it is with the norm that we start to accelerate development, for American educators are rarely interested in maintaining the status quo in achievement levels. Knowing the characteristics of preoperational thought, we selected content for the primary books in this series that will help the child overcome preoperational deficiencies and facilitate development of those properties of logical thought that appear in the stage of concrete operations. Knowing how the child thinks at the stage of concrete operations, we selected content for the middle grades to strengthen logical operations and advance the onset of propositional thinking. As previously stated, we take the position in this series that the development of the highest mental processes should not be left to chance; the school should foster logical thinking in every way possible, and the study of science offers unique opportunities to do this.

Some examples at this point may help to clarify our strategy. Particularly in the first two books, we present learning situations to help the child overcome his tendency to make perceptual judgments and to center on one variable. In Book 1, for example, the pupil is helped to discover that *both* weight at each end a*nd* distance from the fulcrum must be considered in balancing the seesaw; centering on the weight variable is not enough. In Book 2, the young reader has experiences in coo*rdinating* two variables; as he pours sand into containers of different shapes, he learns that "higher than" is compensated for by "skinnier than," so that quantity of matter is conserved. He is also given practice in identifying more than one property in classification problems; he discovers that sounds vary in *both* volume and pitch, and he works out with the teacher a 2 x 2 table (see page 4) to visualize the classification of the sounds to which he is listening.

But what of pupils in the first two grades whose thinking has advanced beyond the preoperational level? For such pupils, logical operations should be made explicit by the teacher so that their use, which may be only intuitive at first, will be strengthened. And the teacher, knowing the logical operations that appear in the average child 7 years old, can make every effort in all of her teaching to strengthen such thinking processes as they appear in pupils in the first two grades.

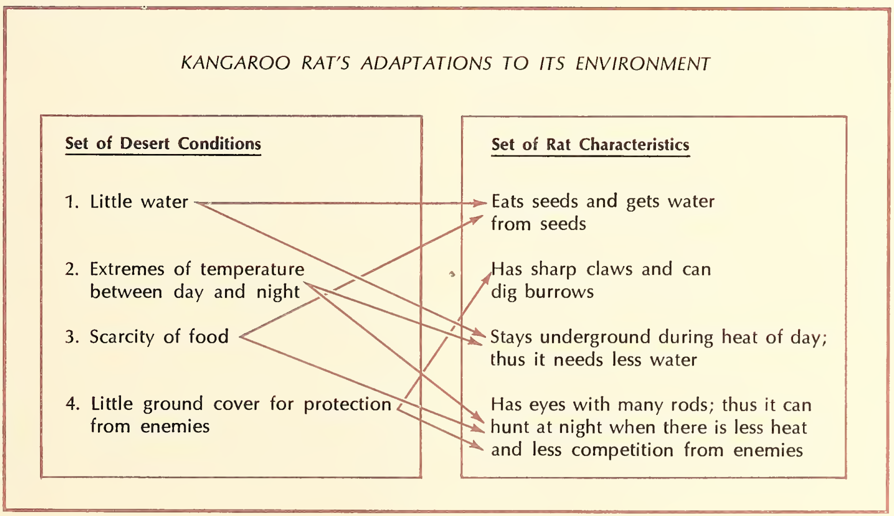
In Books 3, 4, and 5 there is increased emphasis on developing in the pupil these logical operations—combining elements, associating elements in different ways, establishing identity between elements, and reversing an operation—that characterize the stage of concrete operations (normally 7–11 years). There is considerable work, particularly in Books 3 and 4, on classification skills. Such skills began in Book 2, when a pupil learned to describe a specimen by more than one characteristic and then, to identify the specimen as either a butterfly or moth, to make a one-to-one correspondence between the characteristics of the specimen and those of the butterfly or moth. In Book 4, Unit 4, skills become more complex as the pupil learns about hierarchical classification. Fishes, amphibians, reptiles, birds, and mammals can be combined to form a superclass of "animals with backbones." Furthermore, certain things are logically true of the superclass and the subclasses (e.g., each member of the subclass must contain those characteristics that distinguish the superclass plus some others; a subclass is always smaller in number than the superclass.

Logical thinking is also demanded of the child in questions in the text or in the teaching suggestions.

Note the logical processes involved as a third grader attempts to answer the teacher's, "Can you give me an example of an animal that lives on the desert and explain how the animal can live in such an environment?" The pupil has read the unit "How Animals Live," Book 3, Unit 4, from which he learned about many animals adapted to many different environments. To answer the question, he must first combine elements that make up a set of desert conditions: little water, extremes of temperature, scarcity of food, little ground cover. He remembers the kangaroo rat as living on the desert, and combines elements that make up a set of rat characteristics: eats seeds and gets water from seeds, has sharp claws and can dig burrows, stays underground during heat of day and so needs less water, has eyes with many rods and so can hunt in the cool of the night. Then the pupil must set up a correspondence between elements in the desert-conditions set and elements in the rat set. If for the elements in the first set there are corresponding members in the other set, establishing an identity, then he knows the animal is adapted to desert living.

Logical operations continue to be emphasized in Grades 5 and 6, but in increasingly more complex situations. We can find many examples of operations particularly in the physical science content in Books 5 and 6. The development of the speed-time-distance relationship in Book 6 is a case in point. Note that the pupil must now see one variable as a function of two others and work out relationships among the three by using not one but several logical operations (reversibility, for example: if $s \times t = d$, then $s = d/t$; identity, as he puts in the correct numbers for the letter symbols).

Beginning in Book 5 and increasingly in Book 6, content encourages the pupil to do propositional



thinking. For example, in the introductory unit to Book 5, the reader is introduced to the specifics of scientific methods. He has, of course, been raising questions and doing "experiments" in the first three grades; he has even had practice in controlling certain factors while he experimented with another. In Book 2, for example, in the unit on heat, pupils experiment on the insulating qualities of different kinds of cloth. The size of the cloth and the temperature of the water to be protected are kept constant. But the question, "Does the color of clothes make a difference (in keeping us cool)?" is not stated as a hypothesis for testing. It implies a concrete operation, but it does not spell out the specifics for testing. It does, however, provide readiness for the fifth grader's encountering, in Unit 8, Book 5, the experiment, "How Do Dark and Light Colors Affect the Absorption of Heat Energy?"

There is one last point to consider in using the content of *Science for Tomorrow's World* to improve thinking processes. As Piaget has shown, the child deals less with the concrete and more with the abstract and the formal as thinking processes mature. We recognize this developmental change and have taken it into account in our planning to facilitate the appearance of abstract thinking, but we do not emphasize the formal expression of generalizations prematurely. There are many opportunities in the primary grades for pupils to deal with functions in a concrete way. In Book 2, for example, page 138, the pupil carries out an activity in which he discovers that the loss of heat over time is a function of the insulating properties of the protective material. This discovery as stated, however, is beyond the comprehension of most second grade children. Instead, the child of 7 summarizes in a concrete fashion: "With a wrapping made of wool, water doesn't cool off as fast as with wrappings made of cotton or rayon." In keeping with developmental theory, we reserve the more formal and abstract expressions of generalizations for Book 5 and Book 6.

Implications of Cognitive Theory for Activities and Illustrations

Cognitive theory is useful not only in planning content and grade placement, but also in planning learning activities and experiments and in designing special illustrations for tests. The reader will recall that in Piaget's theory, the first stage is the sensorimotor, where the infant may be said to "think with his muscles." While language changes the mode of thinking, the need for a motor component as an underpinning for certain concepts does not disappear with the advent of speech. Bruner in particular has noted the importance of motor activity as a first step in concept building. In this series we have recognized the importance of sensorimotor experience in planning learning activities. No verbal description of how gears work can substitute for the actual manipulation of gears (See Book 2, p. 52). No verbal description can convince the child that the image formed in the retina of what he is seeing is an upside-down image, but let him try building a pinhole camera (Book 6, Unit 6), and he has built into his sensorimotor system a basic understanding of the concept.

Activities with a motor component are not new to science, but what is new is that we now have a rationale for which concepts need this kind of sensorimotor underpinning. Concepts from the physical sciences, where two different displacements occur at the same time, need a motor component. The activities in Books 2, 3, and 6 in the units dealing with concepts of forces and motion contain many examples of such displacements. Sensorimotor activities are often needed, also, to correct misconceptions children have built up. Cognitive theorists have provided us with information about which concepts children are likely to be confused about. In the process of living and adjusting to his environment, the child has been dealing with such phenomena as time, matter, space, light, heat, motion, and electricity, and has more likely than

not built up misconceptions around them. Most children, for example, think that a steady push on an object results in a steady speed. The sensorimotor experience of feeling acceleration in the wagon one pushes with a steady push (Book 2, p. 39) *really* convinces the child in a way that telling him does not. Similarly, most children find it hard to believe that a ball flicked off from a table top and one dropped over the side at the same time will both reach the ground at the same time (Book 6, Unit 3). Understanding that a missile has both a horizontal and a vertical component of motion begins with a sensorimotor experience. (Book 5, Unit 8). And the future student of high school chemistry who has spent time in elementary school constructing models of atoms (Book 5, Unit 6) will find that the theory of chemical bonding comes naturally to him; he can imagine a model of the oxygen atom from his experiences.

Note that each of the activities mentioned helps to correct a misconception or to build a mental image of how something in the physical world *works*. Too much science-teaching time has been wasted in the past on activities with no foundation in an important science concept. Simply building a space station with model rockets in the classroom cannot be justified in terms of its cognitive value. While the activity has motor components, it probably generates more misconceptions than it clears up and contributes nothing to an understanding of the physics of space travel.

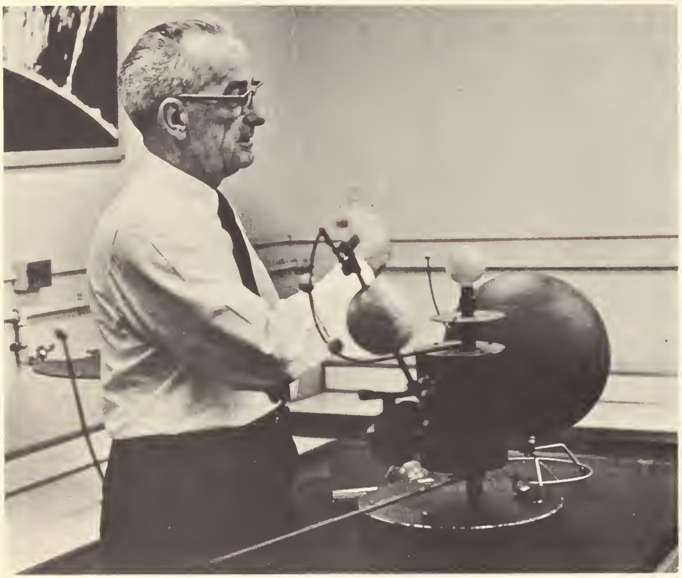
Following the sensorimotor experience (or assuming one in some cases), Bruner describes an *iconic* step in concept-building. After "meaning in the muscles," the child must build a mental image of what it is he is acquiring knowledge about. In this series we have aided the development of this step in the type of illustration used in special cases. The first grade pupil is introduced to the concept of a system in equilibrium through a sensorimotor experience with the seesaw. Then *diagrams* of the system are presented, with distance and weight clearly indicated as the variables. The diagram serves the function of giving the child a mental image of the essentials in the system. It is a pared-down version of the illustration showing actual children seesawing. In Book 2, force diagrams are used, again after a sensorimotor experience, to show both size and direction of the force in question. In Book 6, physical experience involved in understanding time-distance relationships is provided in graph making, the end-product of which then serves the image-building function. In Book 6, Unit 1, also, the learner becomes acquainted with vectors and builds a mental image of velocity with vectors.

With the proper sensorimotor and mental-image underpinning, the learner can then go on to deal with a concept symbolically—that is, with language. Like adults, the pupil who has difficulty in understanding the sentence, "The intensity of light varies inversely with the square of the distance from the source," falls back on sensorimotor memories. If he has actually worked out activities involving the inverse-square law, then he has some "feel" for what the term means. If, in addition, he can also bring to mind a mental image of a diagram of the inverse-square law applied to light, then the sentence takes on additional meaning.

Motor activities, mental images, language—all three steps are not necessary for all concepts. For some concepts, pupils bring with them to school a strong sensorimotor, mental-image foundation, and are ready for the symbolic step. But for other concepts, where the foundation has been missing or faulty, one or both steps are essential. With many concepts, as Piaget points out, knowledge is deformed by a purely verbal approach. Teachers are being advised today, in science teaching, as in all teaching, to spend more time to teach what used to be covered in a few minutes with a few verbal statements. The advice is good—provided the teacher picks the right concepts to concentrate on, and provided the extra time is spent wisely on those steps that build readiness for the verbal stage.

PROBLEMS OF MOTIVATION

Psychologists are generally agreed that motivation is the first essential to learning. If pupils are to learn science, they must first *want* to learn; they must be motivated. However, there are a number of misconceptions with respect to how a state of motivation can be induced. Some teachers confuse motivation with external stimulation supplied to interest children in a lesson. Thus one teacher says, "But I have no trouble in getting my children motivated. I just produce a few pieces of equipment and tell the class we are going to have an experiment, and they are all interested."



Readers will agree with the teacher that children are immediately attentive when an experiment is proposed, but teachers will also recognize that interest in observing an experiment does not necessarily lead to motivation to learn important science concepts. The behavior of children who receive chemistry sets for a holiday present is a case in point. Many a child delights in mixing the chemicals and watching the resultant change in color or state of matter, but for too many it is the magical "result" that intrigues, rather than the chemistry of the change.

For the psychologist, however, motivation is intrinsic to the organism. It is no secret that even the very young infant learns spontaneously and enjoys the process. Furthermore, he is motivated to learn even when there is no adult present to supply initial stimulation. A ten-month-old baby who wants a toy that is out of reach on a cushion in his crib discovers that by pulling on the cushion he can bring the toy within grasp. He is learning that one can use tools (the cushion) to extend the arm to reach objects in space. The motivation for the learning came from within.

Teachers, too, can give many examples of intrinsic motivation. In Book 6, in the unit entitled "The Nature of Light," an activity is described involving use of a homemade ripple tank to study the behavior of light waves. Sixth grade children with access to this equipment have been observed before school and in free time, placing obstacles across the tank or inserting sharp-edged rulers below the surface of the water, to see what happens to the waves they create with a dowel stick. Fourth grade children studying electricity hurry to the science table when assignments are finished, to experiment by winding wire around a nail for so many turns to find out the effect upon the strength of an electromagnet. There appears to be a basic urge to explore, to find out how the environment

can be changed, and to learn what consequences flow from these changes. When this motivation to interact with the environment is present, the child carries on activities with considerable persistence, getting interesting feedback from his efforts and acquiring knowledge in the process. In the language of Piaget, the child assimilates and accommodates, restoring mental equilibrium when accommodation has been achieved.

It is not difficult to find examples of self-motivation in pupil behavior. The problem for the teacher, however, is to set the stage so as to produce this kind of behavior. More specifically, it is the problem of how to induce intrinsic motivation so that the pupil learns what the teacher wants him to learn.

Let us consider the case of a fourth grade teacher who is about to teach a unit on sound. Among the concepts that she wants pupils to acquire are: (1) In order for sound to be produced, something must vibrate; (2) For human beings to hear a sound, vibrations must occur between sixteen times and twenty thousand times a second; (3) The kind of sound one hears depends on the number of vibrations. We know that pupils will acquire these concepts through a self-regulatory process, but what can the teacher do, what stimulation can she furnish, to get the process started?

Theorists of learning have identified the elements that make a situation stimulating and that induce intrinsic motivation. One such element is that of novelty. A relatively less familiar situation is more stimulating than the familiar, and human beings (lower animals, too) clearly prefer the novel to the well known. The situation, however, must not be too novel, for too much uncertainty breeds fear and withdrawal.

Some theorists prefer to call the stimulating element "cognitive dissonance." By that they mean that there must be a discrepancy between information already stored in the brain and information coming in from an ongoing experience. When incongruity exists, there is a basic urge to resolve it so that mental equilibrium is restored. A pupil may presently believe that the way to make a stronger electromagnet is to make it bigger; bigness and strength are associated in his mind. Thus he would predict that a heavy spike will attract heavier objects than a slim nail. Faced with evidence that contradicts this belief, he then experiments with nails of various sizes and with various turns of the wire to find out what actually increases the strength of an electromagnet. He acts to get rid of the incongruity and to restore equilibrium.

The problem, then, for the teacher who would induce motivation in children is to provide encounters with objects or situations that will be incongruous with information children already have. To provide such encounters, the teacher must first know where children are in their thinking with respect to the concepts to be taught. If the teacher wants pupils to acquire the concepts we have listed for the unit on sound, then the teacher must first know what the pupils already believe about how sounds are produced and what the pupils believe about the reasons that sounds are different in pitch and intensity.

One way to find out what pupils already believe is to ask them. A teacher can start a lesson with questions based on the concepts to be taught. Thus, the teacher might begin with the question, "What makes a sound?" To such a question the teacher is likely to get an answer like, "There's a sound when we hit something." The teacher counters this response by asking, "Are all sounds made by hitting something? Who can give me an example of a sound that is made without something being hit?" Examples such as shuffling a shoe across the floor, rubbing the desk with the back of the fist, speaking, etc., are incongruous with the notion that something must be hit for sound to be produced, and pupils are motivated to find out what *is* the common element in all of the examples that produces sound. A discussion centered around questions designed to expose the incongruity between presently held beliefs and evidence to the contrary can induce motivation to resolve the discrepancy.

Even better than the purely verbal approach to motivation is one involving motor activity. From the motor activity, a pupil can take in information not only through the auditory sense, but through the visual and tactile senses as well. Instead of using discussion and relying upon words to elicit cognitive dissonance regarding how sound is produced, pupils can engage in such activities as vibrating a ruler over the edge of the desk, snapping a rubber band held between the teeth, or observing dry cereal moving up and down on a vibrating drum top. Such motor activities are better than the verbal because (1) they are more interesting; therefore, pupils will be more attentive; and (2) they permit more information to be assimilated (the actual information input is greater than when discussion alone is used). The advantage of the motor over the verbal is only true, however, if the motor activity can produce enough novel stimuli to be motivating. A motor activity from which the child can perceive only stimuli too elementary for his level of cognitive development is obviously a waste of time.

Throughout *The Macmillan Science Series,* many activities are introduced that are designed to induce pupil motivation. These activities take more class time than a verbal discussion, but teachers are urged to take the time for them. Only as the pupil becomes aware of the discrepancy between what he has believed and the actual evidence he is assimilating from an activity will he be motivated to acquire new knowledge. Assimilation is facilitated by activities that permit a multisensory approach rather than a purely auditory approach.

We can summarize the modern approach to motivation as follows:

1. The teacher must have clearly in mind the concepts the children are to acquire in connection with the study of a particular topic. These generalizations are listed for each unit in the Teachers' Guide.

2. The teacher uses discussion or, even better, a demonstration or individual pupil activity to stimulate pupil thinking about a particular concept.

3. The teacher asks questions or redirects pupils' observations in order to reveal any discrepancy between stored information and informational input.

4. The discrepancy is stated as a problem to be resolved in the course of the lesson.

PLANNING FOR INDIVIDUAL DIFFERENCES

As in teaching any other school subject, the classroom teacher must plan for individual differences in teaching science. And as is true in other school subjects, individual differences in reading ability create the biggest problem. A fourth grade class of 30 pupils may have a reading range that varies from second to sixth grade ability. How can the teacher accommodate such a range? Teaching pupils in separate groups as is commonly done in reading and arithmetic is not feasible; there is a limit to the number of separate lessons a single individual can teach in a day's time. Nor is grouping within the classroom desirable, except on a temporary basis, for subjects like science and social studies, if each grouping involves a separate body of subject matter. In these subjects there is a core of concepts that should be part of the curriculum for all pupils. All pupils in a particular grade ought to have the chance to acquire those concepts at the level of difficulty possible for them. Some fourth grade pupils may acquire simpler concepts about energy such as "Energy can be transformed from one form to another in order to get work done," while others may tackle more sophisticated concepts such as, "When energy is transformed, the total energy at the beginning and end of the transformation is the same." Managing such a range is quite possible for the teacher.

To provide for the slow readers, it is necessary to find books at their reading level treating the same unit that is being studied by the rest of the class. This is often possible to do in a subject like science, where many of the same topics are encountered in alternate years or every third year. Motion, for example, is studied in grades 2, 3, 5, and 6; weather is a topic in grades 1, 4, and 5; units on living things appear in grades 2, 3, 4, 5, and 6. Other examples of a spiral organization can be found by scanning the complete Table of Contents, which appears in Part IV. Many schools are operating on a flexible plan with regard to the use of texts, taking advantage of the spiral organization in order to meet individual differences. A sixth grade teacher, for example, who has pupils who are retarded in reading, borrows from the third or fourth grade for the particular unit being studied. She introduces the unit in exactly the same way to the entire class, but after pupils have completed their differentiated reading assignments, she introduces into the class discussion some questions aimed at the less sophisticated concepts covered in the easier book. This part of the discussion serves as a review for pupils who are more advanced in concept development. At the same time, the slow learners have the advantage of seeing the demonstrations and following the discussion of harder concepts, all of which serves as readiness for acquiring the concepts when they are encountered later on. As every teacher knows, it is often the *second* explanation that makes assimilation and accommodation possible.

But what does the teacher do in the case of units *not* covered in an easier book? One solution is to vary the reading assignment, requiring slow readers to read less material. Some teachers work with the slow readers as a group, having the material read silently in small sections and its meaning discussed at the end of each section. Under no condition should a pupil be given a book that is beyond his comprehension, unless special help is also provided. Nothing will stifle pupil interest in science more quickly than a teacher who requires the class to read books that are too difficult. As is true both in social studies and in science, the content lesson is also a reading lesson, and the same principles of reading that hold true when pupils are using readers are valid when pupils are reading science texts.

Of particular importance to slow readers are activities and experiments. Slow learners need even more in the way of sensorimotor experiences than do fast learners. The slow-learning third grade pupil can learn the concept of force only by actually setting objects in motion under varying conditions. There is a temptation because they read so slowly to have slow learners spend more time on reading and less on activities. Reading assignments, however, should be adjusted for these pupils so that they also have time to engage in experimentation.

In the past decade, much has been written about the gifted child and about the necessity of providing him with challenging situations. A great deal of effort has been expended in the direction of providing enrichment activities. Unfortunately, however, so-called enrichment activities too often involve only *busy work;* that is, the activity keeps the child *busy,* but at exactly the same cognitive level that he has covered so far. A bright child can be kept busy working on an animal chart on which he lists animals, names of the baby animals, and where the animals live, but at the same time the activity may offer nothing in the way of intellectual challenge. The gifted child needs enrichment in *depth,* rather than horizontal enrichment. He ought to have the chance to tackle intellectually challenging problems that will lead to the acquisition of concepts more sophisticated than those to which the rest of the class is exposed.

If we agree that the gifted child should have enrichment in depth, the next concern is how to provide it. Because the bright pupil is a good reader, some teachers are tempted to keep him busy with special

reports. He is the person assigned to look up topics in encyclopedias or other reference books; but such assignments are all too frequently carried out by copying lengthy excerpts from the source. Special reports need not, of course, be pedestrian or routine. A book such as *King Solomon's Ring,* by Konrad Lorenz, with its fascinating observations of animals, not only brings additional knowledge to the bright pupil in the fifth or sixth grade who reads it, but is likely also to inspire him to observe systematically his pet goldfish or dog, the birds in the backyard, the squirrels in the park, and other animals in his environment. But all science study cannot be carried on only through vicarious activities; directed observation and experimentation, to discover more advanced concepts or to apply acquired concepts to more difficult problems, should also be encouraged in the bright pupil.

Let us examine two different activities proposed in connection with the study of the unit entitled "How Animals Behave" (Book 6). One activity asks that the student find the answer to the question of whether differences between species or differences between breeds of the same species are greater. Pupils are instructed to carry on a series of observations on dogs and cats—recording the animals' approaches to food, their manner of eating, and their behavior after the food has been eaten. By selecting various breeds in each category, comparisons across breeds as well as across species can be made, and data can be gathered to answer the question. The activity serves as reinforcement for key ideas covered in the text; it is one that can be carried out even by slow learners who, hopefully, will become more aware of similarities and differences in animals. It is structured carefully so that directions can be followed easily. Note that alternative answers to the question under investigation are suggested: either the differences across species or the differences across breeds are greater; the problem for pupils is to find data to support one of the two possibilities—an easy task even for the slow learner.

Now let us examine a second activity suggested in connection with the unit "How Animals Behave." In this activity, the pupils are asked to select a category under which observations of animals might be collected—moving-about behaviors, courting, nesting, taking care of the young, and signaling. First the pupil must decide which category and what questions he will seek to answer about that category. Here, we will be concerned only with the "moving-about" behaviors of animals. A pupil might ask, "What is the effect of temperature change upon behavior? Do animals move faster or slower when the temperature rises?" To find the answer, the pupil must vary temperature conditions, choosing animals such as ladybugs, earthworms, or ants, which would be easy to collect and work with. He must plan and construct a temperature box, perhaps heating one end with an electric bulb while the other is left at room temperature or chilled by a tray of ice cubes. Next he must put the animals into the center of the box and observe their behavior. Then he must use his observations and those of his classmates *to discover key concepts* about moving-about behaviors, checking out the particular variable he has selected for testing and perhaps noting other variables worthy of trying out.

Note that this activity is not structured step by step for the pupil. He is not given a choice of hypotheses for testing; he must use his logical reasoning powers to figure out what is worthy of testing. Nor is he told what to do to test his hypotheses; the plan for experimentation will be a product of his own creativity.

Such an activity can provide the challenge to which bright pupils respond. When they first begin to do independent experimentation, they will need help. The teacher must teach them the process—how to select the variable for testing, how to set up adequate controls, and how to collect data.

To summarize, activities and experiments that place a high premium on logical reasoning and creativity must be provided for gifted pupils. Enough

help should be given so that they do not flounder, but they should be allowed independence in working out solutions to problems.

School Organization and Individual Differences

In recent years many innovations in the organization of the elementary school have been effected to take care of individual differences. Nongrading, team teaching, and dual-progress plans are three such innovations. No attempt will be made here to weigh the advantages and disadvantages of each plan; we will merely point out implications of each plan for the teaching of science.

In the nongraded school, grade labels are removed, and children are assigned to a teacher according to reading level. Thus one teacher of 8-year-old children might have an accelerated class capable of reading fourth grade books, while another, with a slow-moving section, might have pupils reading at the second grade level. Homogeneous grouping, whether on the basis of intelligence test scores or reading ability, has always had an appeal for teachers; teaching would be so much easier and more effective "if only individual differences could be taken care of by some kind of administrative device." Unfortunately (or fortunately, depending upon one's viewpoint), they cannot be. In an accelerated class of 8-year-olds, all the children may be able to read easy fourth grade books, but some can read fifth grade books and some do even better. The teacher must still cope with the problem of providing for those children who are capable of doing more advanced work.

A practical method of obtaining appropriate reading materials is to borrow books on the same subject from higher grades. Many teachers are reluctant to do this for fear that the teacher of the higher grades may say, "But what will they read when they are in *my* room?" The problem is one of coordination within a school so that plans are formulated to enable pupils to encounter challenging materials each year. In many schools, teachers pass along a list of the texts read in one year, so that the next year's teacher can plan realistically. In place of assigning texts according to average reading level, as is commonly done in nongraded schools, a teacher can select texts that will take individual pupils higher on the reading ladder. In place of a single text at one grade level, a teacher will have two or more levels to use with a class. Junior high school texts may be introduced into accelerated classes of twelve-year-olds if the need occurs.

Nongrading is a vertical form of organization of the elementary school; team teaching represents a horizontal form. In some schools, team teaching differs little from departmentalization, with different teachers who work as a team assuming the responsibility for teaching different subjects to the same children. As originally conceived, however, a team consisting of a master teacher and several assistants would be responsible for the instruction of about sixty children. The master teacher in a fourth grade might make a presentation to the whole group or conduct a demonstration, while assistants working with no more than fifteen children would supervise reading assignments and follow-up activities.

Team teaching offers certain advantages for science instruction, particularly in its provision for small-group work. The ratio of one assistant to fifteen pupils means many more opportunities for pupil participation in asking and answering questions and in engaging actively in experiments. Whether or not such opportunities are utilized depends, of course, on careful planning by the team. The practice of giving large group lectures or demonstrations, however, needs to be examined critically. It is a rare teacher, indeed, who can hold the attention of large groups of immature pupils for the length of a science lesson. Where team teaching is in vogue, it is better to confine the whole-group sessions to demonstrations requiring

much time to set up; these sessions should have a fast enough pace to ensure maximum pupil attention.

The dual-progress plan—another plan of organization—organizes the school both horizontally and vertically. For children above the third grade, the day is divided into two parts: graded and nongraded. Pupils spend the graded half of the day with a core teacher who teaches language arts and social studies. During the nongraded half of the day, subject-matter specialists take over, including one for science and arithmetic. For special subjects, children are grouped not according to age or grade, but according to aptitude, interest, and achievement. A fourth grade pupil, for example, if science is one of his strengths, might find himself with older children in the science class. For special subjects in which he is weak, he might find himself with younger children. Thus the plan provides for intraindividual variability—a distinct advantage in teaching a subject such as science where talent may become evident in the intermediate grades. An additional advantage is that the special teacher is usually better prepared in the subject matter and therefore presumably able to do a better job of building concepts.

TEACHING SCIENCE TO CULTURALLY DISADVANTAGED CHILDREN

There are teachers in both rural and urban areas of the United States whose classes consist almost entirely of children of the poor. These children present special learning problems, for their impoverished environment has not provided experiences that help mental structures to develop and intelligence to grow. Their homes lack the toys, books, pencils, paper, and mechanical equipment that offer opportunities for discovery. Their parents, themselves disadvantaged as children, lack the knowledge and skills, as well as the facility with language, to call children's attention to phenomena or to answer questions and raise problems; thus, it is difficult for them to furnish their children with science information and to make the children more curious about the world.

In his day-to-day living, the middle-class child has countless experiences that provide readiness for science. His picture books provide training in observation, sharpened by the mother's comments as she calls attention to details of size, color, shape, and cause-and-effect relationships. He takes a bath and observes floating objects in the tub. He goes for walks with parents who comment on shadows, budding trees, a squirrel's nest, how a woodpecker gets its food, and what the position of the sun in the sky tells us about the approach of suppertime. By the time he enters school, the middle-class child has developed mental structures upon which he can draw for solutions to new problems. The lower-class child, lacking the simple mental structures because of environmental limitations, often cannot grasp the more difficult problems with which he is confronted.

There are three ways in which the teacher can help to compensate for a child's impoverished background. First, the teacher must provide a rich language environment for the child. Language facilitates the development of logical thought. A child who doesn't know the names of domestic animals as common as "cow" is obviously going to have difficulty in learning the concept of "animal." A child who lacks the vocabulary to describe dimensions is not going to be able to deal adequately with the notion that as one dimension gets longer, another gets thinner.

The first two books in *The Macmillan Science Series* are illustrated profusely. The teacher can use the pictures to build vocabulary. The teacher can supply labels not only for objects but also for the properties of the objects—shape, color, texture, size, and weight. The teacher can introduce comparative terms such as "taller than," "heavier than," "darker than." The teacher can teach the terms to describe length, width, depth, weight, and other dimensions. The child who knows the terms is more aware of properties of

objects in his environment, and these can help him progress beyond the stage of sizing up an object in terms of whatever variable stands out perceptually.

Beyond the primary grades, the teacher must continue work on vocabulary development. Interestingly enough, it is not the technical vocabulary (e.g. "atom") that presents a problem (provided, of course, the teacher presents the technical terms with proper background); it is the vocabulary to carry on ordinary life activities, which should have been built during the early years, that is lacking. The child learns "pendulum," but he doesn't know the phrase "back and forth" to describe its movement. Getting children to talk about what is going on as they carry out experiments reveals these deficiencies. To counter this situation, the teacher can supply the terms, have the child use them, and review them in context from time to time.

The second recommendation for teaching science to culturally disadvantaged children is to provide more, not fewer, sensorimotor experiences than for middle-class children. The culturally deprived child cannot learn science solely by reading about it. He does not bring to the written word a reservoir of cognitive structures built up out of firsthand experiences. To understand the physical world, he must act upon it. There are 9-year-old culturally disadvantaged children who are *not* mentally retarded, but who do not know that if someone drops an object into a glass of water, the water level will rise. It is not enough for the child merely to read about the effect of one's actions; the child must experience it firsthand, assimilating information directly from the activity. Thus, in Book 2, if the disadvantaged child is to understand gears, he needs to use an eggbeater (a new experience for most children of that age) and observe how the gears are used to turn the beaters. Even more important, he needs to construct models of physical processes. As he makes and operates the endless belt described on pages 54 and 55, Book 2, he can see how, when one wheel is turned, the belt is made to move. He can see the force of the first moving wheel carried to the second. Such an experience builds the cognitive structures necessary to comprehend how a force is passed from one part of a machine to another part some distance away, and how twisting the belt into a figure eight makes the wheels turn in opposite directions and so changes the direction of the force.

Teachers will find additional activities included in the teaching suggestions at the sides of each page of text. Those involving actual motor activity are particularly appropriate in compensatory education.

The third suggestion for helping disadvantaged children is to build up their background of general information. Even at age 10, these children, in response to questioning, are likely to say that a duck is not a bird because ducks can't fly, and that birds and ducks can't be related because birds don't swim. Children can glean a great deal of general information from attractive picture books that are placed on the science table. One fourth grade child very nicely solved an animal-classification problem on the basis of information assimilated from picture books. As he put it, "I know ducks are birds because I could see in the pictures that there were some things the same, and I figured out that if it's got feathers and wings it's got to be a bird, and it doesn't count if it doesn't fly." In Piaget's language, equilibration occurred; the boy had given up an earlier, erroneous notion and accommodated the new information being assimilated.

Note that in all of the examples cited above there are opportunities for furthering logical development. The teacher can emphasize whole-part relations when discussing pictures with children. Relative terms such as "longer than" and "thinner than" aid children in understanding that a change in one dimension may be compensated for by a change in another, with resulting conservation. Testing of disadvantaged children at the University of Illinois reveals that they are lower on tests of logical development than middle-

class children. Compensatory education must include special attention to ensure the optimum development of logical processes in disadvantaged children.

FIELD STUDIES IN SCIENCE TEACHING

Science becomes meaningful for children only as it helps them interpret their environment. Classrooms, science books, audiovisual materials, and laboratory equipment are not the only means by which this purpose is to be achieved. At best they represent the beginning of the process. Ultimately, what is learned from a science book, a motion picture, or a laboratory demonstration must be applied or used in situations beyond the classroom if it is to have permanent educational value. Field studies are planned learning activities that take place outside the classroom.

Teachers often assume that once a science concept is dealt with in the classroom, pupils will use it on their own for out-of-classroom activities. It is possible that a few may do so, and rather extensively. Some may use the concept on a relatively limited scale. But many of the pupils may never relate the pertinent concepts to the things that are happening about them. For example, in a unit on conservation, pupils may read about ways in which runoff water erodes unprotected soil. They may view a film that shows the process taking place. They may even do a classroom experiment to measure the soil eroded from protected and unprotected surfaces by a measured quantity of runoff water. But what happens when the pupils *leave* the classroom? Do they recognize places where soil is being eroded? Do they suggest ways in which the erosion can be controlled? More important, do they attempt to do something about it? If the science of soil conservation is to become meaningful to pupils, learning about it must extend beyond the classroom into actual situations where the phenomena are taking place.

After considering the question of how science concepts dealing with soil conservation should be made more meaningful to pupils, a teacher might decide that three types of field studies would be appropriate.

One type has to do with locating places in the schoolyard or in nearby spots where soil is being eroded. Before the pupils started on their search, the teacher would alert them to the kinds of evidence that indicate that soil is being eroded. These include soil that has been washed onto sidewalks, roots of trees that have been exposed by the erosion of soil, small gulleys showing that erosion has started, and deltas of soil that have been deposited by water. After pupils had learned how to spot the evidence, they would proceed as a class or in small groups to locate places of erosion in the area. Following the group activity, pupils could be asked to look for other places near their homes and report their findings to the class.

A second type of field study might be to select one of the places where soil erosion is taking place and plan ways of stopping it. Ideally, this should be a place near the school where everyone can take part. Some pupils might undertake individual control projects in their own communities.

A third type of field study might be to visit a place where a planned procedure is being used on a large scale to control soil erosion. This might be a farm, a public park, a housing development, or new highway construction. The persons who are responsible for the plan would answer pupils' questions.

Based upon the above descriptions of three types of field studies having to do with soil erosion, it is reasonable to expect the following educational purposes to be accomplished by such activities:

1. Reinforcement of science concepts taught in the classroom by observing the concepts in action.

2. Development of the habit of viewing the environment in the light of concepts introduced in the classroom.

3. Recognition of situations that represent problems in need of solution.

4. Personal involvement in solving such problems and the development of the required skills.

5. Acquaintance with efforts to deal with such problems.

6. Acquaintance with agencies and people who assume responsibility for the problems in question.

There are a number of matters that must be considered when using field studies in teaching elementary school science.

Background Preparation

Generally, it is desirable to develop the pertinent conceptual background before undertaking a field study. In the above examples, reading about soil erosion and its causes (Book 3, "Our Planet Earth"; Book 6, "Life on the Earth"), viewing a film that shows how the process takes place, performing experiments to determine the effectiveness of plant cover in reducing erosion, and discussing the facts involved would help to build the essential conceptual background for the three field studies. This would give children the "eyes" with which to observe and interpret their observations.

Comprehensiveness of the Field Study

The field study should not be so comprehensive that teachers and pupils "get lost" in carrying it out. In the above examples, there were three distinct, manageable phases involved. Each phase had a specific purpose to accomplish. The first phase had to do with locating places where soil erosion was taking place. The second was the selection of one of these for further study. The third was finding out how other people solve the problem on a larger scale.

Personal Commitment

Wherever possible, the field study should provide for a personal commitment from each pupil. In these studies each pupil was encouraged to locate places where soil erosion was taking place in his neighborhood and to share his findings with the class. In addition to work on the class control project, individual pupils were encouraged to undertake small-scale control in their own neighborhoods.

Preplanning

Preplanning can pay high dividends in accomplishing the specific purposes of a field study. There are two aspects to preplanning: the teacher's preplanning by himself and the preplanning that the teacher does with his pupils. It is reasonable to assume that preplanning on the part of the teacher would lead to the decision to conduct the three field studies in the sequence described earlier. He would be responsible for planning and making decisions regarding the feasibility of various approaches to each study. He would also have the responsibility for making administrative arrangements. He would then involve his pupils in planning the details.

Prior to the first field study (that of locating places where erosion had taken place), the teacher and pupils would work together in deciding upon the kinds of evidence that they would look for. They would make plans for recording the evidence and indicating the places where the evidence was found. They would plan how to proceed from the classroom to the places they were going to visit. They would plan how the time allotted for the study would be used.

Field Studies as Investigations

Field studies should be carried out as investigations rather than as idle excursions away from school.

To be an investigation, a field study must have a clearly defined purpose. Although children will use many skills, such as those involved in communicating, observing, comparing, classifying, interpreting, and evaluating, the development of these should not become the primary purpose of a field study carried out as an investigation. Its purpose should be to obtain information and/or to solve a problem.

In the first field study on soil erosion, the purpose was to locate places where erosion was taking place. In the second, it was to suggest ways to control erosion in one of the locations. In the third, it was to find out how erosion is controlled on a large scale. The purpose of each investigation should be made clear to all who are involved in it. Each activity in the investigation should relate clearly to its purpose.

Where investigations involve the collection of specific data, plans should be made for recording them in an organized manner. The organization will be determined by the manner in which the data are to be used. For example, if the field study is to locate places where soil is being eroded by runoff water, a decision will have to be made regarding the area to be explored. Suppose it were limited to the school grounds or to a vacant lot near the school or to a three-square-block area adjacent to the school. Before the exploration was begun, a decision would have to be made regarding the method of recording the sites of erosion once they were found. In this case it would be reasonable to use a mapping method. A map would be drawn of the area. The map would be duplicated and each pupil given a copy. As erosion sites were found, they might be located on the map by placing an X at the appropriate spots. Some legend might even be used to indicate how severe the erosion was at the different sites. These data could then be referred to in selecting the one area that would become the test site for the control study.

Where the investigation has to do with solving the erosion problem in one of the places, other methods of recording data might be used. First, a record should be made of the nature and extent of erosion at the selected site. Next, the method by which the erosion is to be checked should be recorded. Finally, the report should be concluded with statements regarding the apparent success of the method used.

Where the investigation has to do with finding out what methods are used to control erosion on a large scale, the data would probably be recorded as answers to a list of questions prepared before the trip was taken to the site. Different pupils might be given the responsibility for obtaining answers to certain of the listed questions. After the answers were obtained, the study would be concluded by a written report that explained a method of controlling soil erosion on a large scale.

Each investigation should culminate in something that represents a record of what was accomplished as a result of the investigation. Investigations should run full cycle, from purpose back to purpose. The findings of the field study should be reported in ways that show how the purpose of the field study was accomplished.

The Size of the Group

Where it is impractical for the entire class to participate in a field study, a similar group of pupils or an individual pupil might conduct the study for the class. Suppose that the problem of transportation to the site where large-scale soil conservation was being practiced precluded the possibility of the entire class's making the trip. The teacher or one of the parents might take one or more pupils to the site. They could obtain answers to the questions that the class had prepared. Arrangements might even be made for them to take pictures to illustrate the various practices. These could be used in making a report to the whole class.

There are various ways in which teachers can learn about the types of field studies that might be

carried out by their pupils. In *Science for Tomorrow's World*, field studies are suggested at appropriate places in the pupil's text and in the Teachers' Annotated Edition:

BOOK 1
Visit a pet shop (p. 99).

BOOK 2
Compare the warm and cool ground outside your school or house (p. 111).

BOOK 3
Visit a planetarium (p. 35).
Plan a trip to a museum (p. 89).
Visit a food market or a farm (p. 219).

BOOK 4
Visit a public library (p. 131).
Visit a fire station (p. 309).
Visit a water purification plant (p. 314).

BOOK 5
Visit a botanical garden (p. 75).
Visit a drug company (p. 163).
Visit a textile factory (p. 208).
Visit a weather station (p. 261).

BOOK 6
Visit an electric utility company (p. 140).
Visit an astronomical observatory (p. 190).
Visit a biome (p. 296).
Visit a zoo (p. 341).

The soil erosion field studies described earlier come from this source. Generally, schools which have detailed courses of study include field studies among the suggested learning activities. *Science and Children*, published by the National Science Teachers Association, 1201 Sixteenth Street, N.W., Washington, D.C., is designed primarily for elementary school teachers. Each issue contains articles that include out-of-classroom activities in elementary science.

Some school systems supply teachers with guides to sites in the community where field studies may be conducted. These guides include such information as:

1. Name of site.
2. Location and directions for reaching it.
3. Age level for which its use is best suited.
4. Science topics to which the use of the site is related.
5. Data which might be obtained at the site.
6. Specimens or materials that could be collected.
7. Times most suitable for visiting.
8. Person with whom arrangements should be made.
9. Special regulations.
10. Safety factors to consider.
11. Evaluation statements made by those who have previously visited the site.

Sometimes good ideas for field studies can be obtained by talking over the problem with other teachers, especially secondary school science teachers. Finally, elementary school teachers should not underrate their own creative imagination in discovering field studies that will add a new dimension to their science teaching.

Evaluating Field Studies

After the field study is completed, it should be evaluated by teacher and pupils. One of the first questions to ask in evaluating a field study is, "Did it accomplish its purpose?" Where it failed, the next pertinent question is, "Why?" The answers to this latter question then become clues to the safeguards that should be exercised in the next field study.

Suppose, on their first soil erosion field study, children failed to find the evidences of soil erosion that had been anticipated by the teacher. This might indicate that the teacher had not done a careful job in selecting the area to be studied. It might mean that the children had not been properly briefed regarding the kinds of evidence for which to look. It might also mean that, for one reason or another, pupils had not observed carefully enough.

Suppose, on their second field study, the plan developed by the pupils did not control the erosion. This might be accounted for by the fact that they had not considered all causative factors and thus had not provided controls for some of them. It might also be that the plan was a good one, but they failed to carry out some phase of it.

Both teachers and pupils experience great disappointment when projects such as field studies do not turn out as expected. Both are tempted to forget the whole thing and to go on to something else. But there is always a reason for things not turning out as expected. To find the reasons and to carry out another study is an equally important educational experience. From it, pupils learn that one must have as many pertinent facts as possible before making his plan, and furthermore that his plan should take all pertinent facts into consideration. Finally, the pupil learns that the study must be carried out in terms of each detail of the plan.

Local Conditions

The use of field studies has to be adapted to local conditions. One local condition has to do with the availability of sites. The soil erosion field studies described earlier are those that could be carried out in most school situations. Even for schools located in cities where there are asphalt-covered playgrounds, the teacher and class should not have to go far from school to find a vacant lot or a small park area where soil is exposed. And wherever soil is exposed, there will be erosion. Somewhere, in practically every community, new buildings or houses are being constructed. Highway construction is taking place across the country. In these places, soil is being exposed to erosion.

Records of Field Studies

A file should be maintained of all completed field studies. The file, prepared by the teacher, might consist of one-page summaries of each field study, supplemented by a copy of one of the better reports written by the pupils. The teacher's summary should include the following information:

1. Purpose of the field study.
2. The science unit to which it is related.
3. The site and person with whom arrangements were made.
4. The number of pupils involved.
5. Persons who assisted with the study.
6. The date the study was begun and the date it was completed.
7. Problems encountered, along with notes as to how each problem was handled.
8. What pupils learned from the study.
9. Points to keep in mind in planning another, similar study.

Records such as these will be helpful not only in future planning of field studies, but also in sharing ideas about field studies with other teachers. The sharing might be in your own school or with many elementary school teachers through an article written for a journal such as *Science and Children*.

USING THE COMMUNITY

There are a number of good reasons why teachers should make maximum use of their communities in teaching science. The ways in which science relates to the lives of people can be effectively demonstrated by activities taking place in the community. In many communities there are people who are uniquely qualified to serve as authoritative sources of scientific information pertaining to many of the topics studied in class. Local institutions such as libraries, museums, planetariums, parks, zoos, and aquariums have been established as sources of information not usually available elsewhere in the community. Finally, through proper use of community resources, the people involved become better acquainted with the educational program of the school and the ways in which teachers are attempting to implement it. This is particularly important in elementary science, because science was not taught in the elementary school when many of the community's adults were pupils themselves.

Environmental Resources

Science teaching should begin with the ongoing experiences of children. It should move to other experiences from which children can gain more sophisticated insights or concepts. Finally, the new concepts should be used to reinterpret aspects of the immediate environment. Science then becomes a way of making the environment more meaningful.

The child's immediate environment is the community in which he lives. It is both a natural environment and a man-made environment. His natural environment includes the sky above him, the nearby woods and fields, streams and ponds, rain, wind, sunlight, clouds, snow, rocks and soil, plants and animals, and other people. His man-made environment includes school buildings and houses; bicycles, automobiles, trucks, tractors, and airplanes; highways, railroads, and streets; telephones, radios, and television; rockets and spacecraft; filling stations and airports; stoves and refrigerators; baseballs and bats; factories and stores; and even merry-go-rounds and Ferris wheels. Such an analysis as the above could be extended almost indefinitely. What is indicated is that the community represents a laboratory with almost unlimited resources for teaching science. In fact, the environmental resources in any community are so extensive that teachers may find it difficult to know where to begin.

Application of Concepts

You could begin by writing the title of each unit in your science text on a separate sheet of paper. Under each title, list the topics that are dealt with in that unit. Next to each topic, list activities in your community that might be used in helping to teach the concepts with which the topic deals. Here is an example of how this might be done for some of the topics in a unit on forces (Book 4, Unit 2):

UNIT: FORCES

Topics	*Community Activities and Objects to Which Concepts Apply:*
Making things move	Men loading a truck by hand; Men shoveling gravel; Hoist used by a construction gang working on a building.

Forces of different sizes	Bulldozer digging a basement for new apartment houses; Car lift at a local filling station; Automatic door-opener at a supermarket.
Measuring forces	Scales used in weighing baggage at an airline terminal; Scales for weighing trucks at inspection stations on highways; Scales for weighing children in the nurse's office; The recorded weight tests of fishing lines sold in a sporting goods store; Testing air pressure in tires at a filling station; Posted load limits on bridges; Posted load limits on elevators; Anemometer at a weather station.
Keeping things from moving	Brakes on automobiles; Prop reversal for slowing down airplanes; Retaining walls on the side of a steep hill; Plant cover to prevent soil erosion.
Balancing forces	Sanding icy streets; Supports on a stepladder; Timber braces in a mine; Supporting trees to protect from high winds; Bicycle stands; Door stops; Umbrella stops; Scaffolding to support workmen.
Forces have direction	Weather vane to indicate direction of winds; Hitting a baseball, a tennis ball, or a golf ball; throwing a baseball or a bowling ball; shooting baskets.

Going faster	Roller coaster; Streamlined cars; Skiing on steep slopes.
Changing directions	Steering wheels on automobiles; Rudders on airplanes; Handlebars on bicycles.

These are only a few local examples of how certain science concepts are applied. As you search for others, many more may be found. Once the searching process is started, pupils should be encouraged to take part. As pupils find additional examples, the meaning of the concept will become more firmly established in their minds.

The Community as a Source of Problems

The community not only provides many examples of how science concepts are being applied, but it is often a source of problems that require science for their solution. Here is an example of how one class became involved in an interesting local problem. At about the time the class had completed their study of a unit on conservation, an editorial dealing with the disposition of unsightly junked car bodies appeared in the local paper. The editorial proposed that the bodies be dumped into one of the Great Lakes—Lake Ontario. According to the editorial, this would remove an eyesore from the landscape and at the same time provide cover at the bottom of the lake for fish. In fact it was reported that local fishermen were in favor of the proposal.

Since pupils in this science class had learned about the importance of conserving metals, such as those used in making car bodies, they felt that the plan would be a waste of mineral resources. They believed it would be much better to reclaim the metal, and so they decided to write to the editor of the paper about their opinions. But their teacher encouraged them to check all of the facts involved in the situation before they wrote the letter.

A clipping of the editorial, along with an explanation of what the science class proposed to do, was sent to the United States Department of the Interior for evaluation. An assistant secretary of the Department replied with a two-page letter. Two paragraphs from his letter are quoted below:

> *With respect to the disposal of automobile bodies, it should be recognized first of all that the major part by weight of a junked car—the chassis—is very largely reclaimed, either for used parts or for steel furnace feed, before the unsightly body shell arrives in a so-called automobile graveyard. These shells have little or no reclamation value for several reasons. First, enormously expensive machinery must be maintained at the waste dealer's yard in order to compact the bulky shell into a form that can be charged into a furnace; second, a serious smog problem is involved in burning out organic material like upholstery before the compacting can take place; and third, the extensive electrical systems in modern automobiles introduce enough copper wiring in the shell to degrade the iron and steel reclaiming in smelting. The net result is the absence, in most instances, of a profit incentive for scrap dealers to reduce automobile bodies to a form saleable to steelmakers in competition with metal derived from cheap and plentiful iron ore.*

> *Disposal of automobile bodies in the Great Lakes raises other problems. The Department's Fish and Wildlife Service reports that auto bodies have been dumped offshore into salt water apparently without harmful effects, but without much benefit to the fish because the bodies tend to fill with silt and to lose form through rapid rusting. This Service notes, however, that disposal in the fresh water of the Great Lakes poses other objections, in particular, the absorption of the water's oxygen, during the rusting process, from waters already seriously deficient in this gas for the support of valuable aquatic life because of other wastes.*

It is quite obvious that both the teacher and his pupils, through becoming involved in this community problem, had their concepts of conservation practices, as well as the science involved, extended considerably beyond the unit on conservation that they had studied. In addition, the pupils learned that one should get all the evidence before making a decision about a problem such as this one. At first the problem appeared to be a relatively simple one, with a clear-cut solution. However, it turned out to be much more complex. Finally, they learned how government agencies, such as the United States Department of the Interior, can be sources of information.

Resource People in the School and Community

In some schools, files are kept of the names and addresses of persons in the local community who may be used as resource persons for various purposes. These generally include teachers and other persons in the school. Where a school does not have such a file, it would be well to start one. A good place to begin would be with those who could be used as resource persons in the elementary science program.

In addition to their professional teaching competence, there often are teachers in school systems who have had other experiences that qualify them to serve as resource persons in elementary science. Included among these would be experiences in outdoor recreational activities such as hunting, fishing, bird watching, stargazing, boating, mountain climbing, and swimming; industries such as farming, manufacturing, lumbering, mining, construction, and transportation; institutions such as hospitals; agencies such as the Forest Service, National Park Service, and Conservation Service; and hobbies such as photography, radio, aviation, and even rocketry. There are people, other than teachers, in the community who have had experiences such as those enumerated above and who may be more available during school time. To find all of them becomes quite a problem. In some schools the P.T.A. takes on the job of locating them. This is generally done by sending out a suitable questionnaire to the patrons of the school. Where such an organized search is not possible, teachers may have to rely upon their pupils and other persons in the school to help locate resource people in the community.

Usually there are a number of professional people in communities who, by virtue of their professions, potentially qualify as resource persons in science. These include scientists, engineers, doctors, and nurses. There are others whose business or work may qualify them as resource persons. These include airplane pilots, firemen, laboratory technicians, food processers, manufacturers, builders, and automotive mechanics. A good way to locate others in this latter category is to examine the classified telephone directory of your community.

Museums as a Community Resource

If your school is located in a community that has a museum, you will surely want to use it as a

resource in your science teaching. Your school may have an inventory of the museum facilities available for school use. If it does, you should examine it to determine which ones would be suitable in your science course. If it doesn't, you can write to the curator of the museum for such information. Here is a partial list of exhibits listed in the general guide to one rather large museum:

- Minerals and gems
- Fossil fish
- Dinosaurs
- Ice age mammals
- Insects and spiders
- Fishes
- Amphibians and reptiles
- Birds
- Mammals
- Animal behavior
- Man and his origin
- The natural history of man
- Ecology
- North American forests

From a list such as this, you can select the two or three which you think might be worthwhile for your pupils to visit. Next, you should visit the museum to find out more about the exhibits you have selected. When you do this, plan to spend sufficient time to make a reasonably thorough study of each exhibit. Take notes on points of particular interest.

There are two ways in which you can get your pupils to the museum. Probably the best way is to arrange to take them yourself. If you do, have several parents accompany you to assist in supervising the children. Another way is to encourage parents to take their own children. Whichever way is used, some time must be spent in preparing the children for what they are to observe and how they are to observe it. This is where you will make use of the notes taken during your earlier visit to the museum. From these notes, you can prepare a statement regarding the general nature of the exhibits to be visited and how they are related to concepts that pupils have been studying, or will be studying, in science. Specific suggestions of what to look for should be given. These might be formulated as questions to be answered as students observe the exhibit. If you use the question technique, avoid making a large number of detailed questions. Long lists of such questions often result in children's not seeing the forest for the trees. For each selected exhibit, try to decide on the two, three, or four most important ideas with which it deals. Then formulate questions that will highlight the ideas. Regardless of whether you take your pupils or their parents take them, their preparation for the trip will be much the same. It is doubtful that children can experience anything but confusion from an unselective, unplanned, and unstructured trip to a museum. After the museum trip, there should be a time at school for review and summary of what was learned.

Planetariums as a Community Resource

In planetariums, a projector is used to display the movement of heavenly bodies on a hemispherical, or bowl-shaped, ceiling. The projector can be set to show how the heavenly bodies appear to rise in the east, move across the sky, and set in the west. It can also be used to show how the stars appear to an observer on the earth at various locations from the equator to the poles. Methods of locating constellations and prominent stars within them can also be demonstrated.

If there is a planetarium in or near your community, encourage your pupils to attend one of the demonstrations. Obviously this should be done near the time that they are studying about stars and planets in their science class. Since the director changes the planetarium show from time to time, you should try to keep informed about the current shows.

Planetariums usually arrange special showings for school-age children. It might be possible for you to combine a planetarium trip with a museum trip on the same day. As was the case for museum trips, children should be prepared for their visits to the planetarium. Admission fees are usually charged. However, special rates are given for school groups.

Parks as a Community Resource

Parks serve a number of functions in many communities. They are places where people may go for rest and recreation in natural surroundings of trees, shrubs, grass, streams, and ponds. They are places where people may go to learn more about the living things contained within the park. Parks generally contain a greater variety of trees and shrubs than may be found in any other place in the community. They can thus be used by teachers and pupils to observe various types of plant life and to identify similarities and differences among them. Parks can be used in the spring, summer, fall, and winter to demonstrate how the vegetation changes with the change in seasons. Parks usually have ponds or lakes that serve as a refuge for water birds such as ducks and geese. Because they are protected, the birds have become less afraid of people and can be observed from close quarters. Pupils can observe the forms and shapes of their bodies, their eating habits, and the manner in which they walk, fly, and swim.

Zoos as a Community Resource

From the point of view of children, zoos are among the most popular institutions in communities where they are maintained. Children enjoy observing animals. Visits to the zoo can become significant educational experiences in science if they are properly planned. In planning a trip to the zoo, teachers need to know what animals are kept there, from where the animals were obtained, and how they are cared for. This information can best be obtained by teachers visiting the zoo and having the educational director give them a conducted tour. For a group of teachers, the director may even include a "behind the scenes" tour of the zoo. On such a tour, teachers will be shown how food for the animals is selected and prepared, how animals are treated for injuries and sickness, how cages are cleaned, and how animals requiring special kinds of environments are protected. With background such as this, teachers can plan the zoo trip with their pupils so that it becomes an integral part of their study of science.

Institutional Aquariums as a Community Resource

Institutional aquariums are more difficult to maintain than zoos and, therefore, are not as common. But where they are maintained, they should be used by teachers to reinforce and extend science concepts related to the variety of living things and how living things are adapted to the environmental conditions in which they are found. The recommended procedures for using a zoo also apply to using an institutional aquarium. Because of the cost of maintaining an aquarium, there is usually an admission fee. As is true for planetariums, special rates are usually given to school groups.

Libraries as a Community Resource

Although firsthand experiences in observing, demonstrating, and experimenting are of paramount importance in learning science concepts and learning the methods of science, we should not leave children with the misconception that these are the only ways of learning about science. Books and periodicals are the most commonly used sources for learning about science. This is as true for the scientist as it is for

the nonscientist. Scientists and science laboratories could not be maintained without good libraries.

It is, therefore, important that the practice of using the library be encouraged, rather than discouraged, while pupils study science in the elementary schools. As evidence of the scientist's point of view regarding the importance of using good science books, the American Association for the Advancement of Science and the National Science Foundation publish bibliographies of science books for children. These bibliographies can be obtained by writing to the American Association for the Advancement of Science, 1515 Massachusetts Avenue, N.W., Washington, D.C., 20005.

Librarians report that a very high proportion of the questions that children bring to them deal with science. To provide for this interest, most libraries maintain a good selection of children's books on science. These books can be used for several purposes. They make it possible for children who want to find out more about certain science topics to do so. They supply information on new developments in science. Some deal with selected science topics in greater depth than is possible in a science textbook. Others present interesting biographies of notable scientists.

One of the best ways of finding out how you can encourage your pupils to use library books in science is to visit the science section of the children's reading room in the library in your community. Acquaint yourself with the wide selection of titles. Take out several books and read them. Then tell your children about the books. If this is done periodically, you can be sure that more and more of the children will begin using the library.

USING AUDIOVISUAL MATERIALS IN SCIENCE TEACHING

A great variety of audiovisual materials is being used in the teaching of science. They range from simple line diagrams drawn on the chalkboard by teachers to elaborate motion pictures that cost thousands of dollars to produce. All are designed to enhance teaching and learning through the use of the visual and/or auditory senses.

Audiovisual materials can be used to show objects, conditions, and events that are not immediately or directly available to pupils, thus extending the range of the pupils' classroom experiences. These may include such subjects as the research work of scientists in Antarctica, the earth as seen from a spacecraft, and conditions at the bottom of the ocean as photographed by a submarine camera.

Audiovisual materials can restructure the time and sequence of pupils' activities and experiences, thus making the activities and experiences more effective for educational purposes. Such materials include tape recordings of interviews, which become reliable records of questions asked by pupils and answers given by an authority on a topic being studied in science; pictures taken to produce reliable records of objects or processes observed during a field trip; pictures of the same child at different ages to show growth changes; slow-motion pictures of activities such as running, in which the sequence of body movements takes place so rapidly that it is difficult to observe the details; or time-lapse movies of events such as the opening of a flower bud, which takes place so slowly it is impossible to observe the details of the marvelous processes involved.

Audiovisual materials may be used to demonstrate procedures and to illustrate concepts in science. They can be used to show how to plan and conduct an experiment, to dissect an animal, to use a piece of apparatus, to prepare exhibits, to conduct a science fair, or to write a report. They can be used as an aid in explaining such concepts as the interdependence of living things, action-reaction, electric currents, work, chemical change, adaptations of living things, and practically any other concept studied in science. Audiovisual materials can be used to organize and

integrate concepts dealing with such topics as weather, nutrition, and spacecraft. They can be used as an aid in visualizing such concepts as the enormous solar system and the minute atom.

Types of Audiovisual Materials

There are two general types of audiovisual materials: those that require special equipment in order to use them and those for which no special equipment is needed. The following audiovisual materials require special equipment, such as cameras, projectors, recorders, microscopes, and phonograph machines:

- 16 mm. motion picture films
- 8 mm. motion picture films
- filmstrips
- 2" x 2" slides
- prepared microscope slides
- large transparencies for overhead projection
- recordings, both tape and disk

Among those materials that do not require special equipment are exhibits and models. The remainder of this section will deal with ways in which all of these materials can be used in teaching science.

Motion Pictures

The following list of selected titles, from the catalogue of one of the large producers of educational films, clearly indicates that science subjects are covered extensively by motion pictures and that films are available for every grade level:

FOR KINDERGARTEN AND GRADES 1–3

Animals and Their Foods
Electricity for Beginners
Energy Does Work
How Air Helps Us
How Animals Help Us
How Simple Machines Make Work Easier
Living and Non-Living Things
Rocks: Where They Come From
Sound for Beginners
Winter Comes to the Forest
Zoo Babies
The Big Sun and Our Earth
What Do We See in the Sky?

FOR GRADES 4–6

Air All About Us
Chemical Changes
Color and Light
Energy and Its Forms
Fossils: Clues to Prehistoric Times
Heat and Its Behavior
How Weather Is Forecast
Introducing Atoms and Nuclear Energy
Magnetism
Beyond Our Solar System
Adaptations of Plants and Animals
Fish and Their Characteristics
How Flowers Make Seeds

FOR GRADES 7–9

Airplanes: Principles of Flight
Conserving Our Forests
Electricity: How It Is Generated
Field Trip to a Fish Hatchery
Fire and Oxidation
Electrons and Electronics: An Introduction
Force and Motion
Latitude, Longitude, and Time Zones
Weather: Understanding Storms
Gravity
The Structure of the Earth
Behavior in Animals and Plants
Cell Biology: Life Functions

As is true in selecting any audiovisual material, films should be selected for use in science teaching only when they relate closely to the work at hand.

Furthermore, they should be suitable for the grade level at which they are to be used. Film catalogues carry descriptions of each listed film along with a statement regarding the grade level for which it is best suited. For example, here is a description of the one-reel, eleven-minute color film *Animals and Their Foods* given in the catalogue: "The animals in this film are divided into groups according to the foods they eat: (1) plant eaters; (2) meat eaters; and (3) those that eat both plants and meat. The illustrations explain the basic concept that different animals are suited to eating different kinds of food." Another example is the description for the film entitled *Electricity for Beginners:* "A flashlight that doesn't work leads Frank and Joan to a basic concept: Electricity flows only in a continuous pathway. Simple demonstrations in a hardware store show how electricity can produce heat, light, and magnetism, which in turn can produce motion in a small motor. The film also emphasizes the importance of safety with electricity."

Larger school systems usually maintain an audio-visual center for motion pictures such as those previously discussed. Where this is not the case, films have to be rented from an agency. Under such conditions, teachers often must plan for the use of specific films as much as a year in advance. But it is not always possible to anticipate the exact date upon which a specific topic will be used in a science class. Therefore, the dates for which films are ordered are usually tentative. But the films arrive on the dates ordered and can be kept for only a few days. It is not always possible to coordinate teaching with the prearranged film schedule. When this happens, teachers have to adapt their use of the film to fit the situation. When the film arrives ahead of the time that the topic for which it was selected is being studied, the teacher may find it necessary to use the film as a preview for what is to come in science. When it arrives after the topic has been studied, the teacher may find it advantageous to use the film as a review of the topic.

Much of the success experienced by teachers in using movie films is a direct result of the preparation they make for their use. They select only those films that are related to what they are teaching in science. They read carefully the teaching guide that accompanies the film to become better acquainted with its purpose and content. They preview the film to find out for themselves what it is all about. They prepare a suitable introduction to be used in presenting the film to their pupils. After the film is shown, it is discussed with pupils to make certain that its important points are reviewed and related to the work at hand.

Also available to teachers are 8 mm. cartridge-type film loops, known as single concept films. Such cartridge films require no threading, no rewinding, and only minimal handling. Each cartridge provides about three to five minutes of viewing time, pinpointing and highlighting a single concept. Thus, digestion, the structure of the atom, sound waves, and carbohydrates all might be subjects for the cartridge films. These films, although they do require special, moderately priced projection equipment, are an extremely valuable adjunct to the teaching of a lesson. They enable the teacher to point up a particular aspect of the lesson with ease and clarity.

Filmstrips

There are filmstrips for practically every topic studied in science. Filmstrips have some advantages over movie films. Since they are less expensive, individual schools can have selected collections of them readily available for use in the classroom. It is easy to operate a filmstrip projector. Pupils can participate by asking questions and giving explanations during the time it is being shown. It can easily be reversed to review frames whenever desirable.

Some filmstrips are accompanied by sound records. The sound accompaniment is usually commentary for

each of the frames and must be synchronized with the pictures by the operator of the projector. The accompanying sound commentary covers all important points with which each frame deals. Printed commentaries are also supplied with filmstrips so that the teacher may read as the filmstrip is being shown. The use of a printed commentary gives the teacher the advantage of being able to pace the showing of the filmstrip to accommodate the reactions and questions of the viewers. It is desirable for teachers to preview the filmstrips before classroom use. Furthermore, only those filmstrips that relate closely to the topics being studied should be selected for use.

2″ x 2″ Slides

These are transparencies whose dimensions are 2 inches by 2 inches. Generally they are color transparencies. Most of the advantages of filmstrips also hold for 2″ x 2″ slides. Also, while the pictures in a filmstrip are arranged in a definite sequence, it is possible to arrange the 2″ x 2″ slides into whatever sequence seems appropriate at the time. The 2″ x 2″ slides have another advantage in that teachers and pupils can take their own pictures with the proper camera and use them to make up their own classroom collection of slides. Here is a list of subjects, each of which could be made into a picture story using 2″ x 2″ slides:

Seasons in Our Town
Machines Make Work Easier
The Care of Animal Pets
Evidence That Air Is a Substance
Increasing and Decreasing Friction
Evidences of the Water Cycle
Rates at Which Different Seeds Grow
Forces
Units of Measurement

Using the Microscope

The compound microscope is the type most commonly used in classrooms. This microscope has an eyepiece lens and an objective lens, each one magnifying the image of the object to be viewed. Light strikes the mirror near the base of the microscope and then passes through an opening in the stage. The light continues through the objective lens, the tube, and the eyepiece until it reaches the observer's eye.

To magnify an object, it is necessary that only a *very thin* segment of the object be used. When magnifying onionskin, for example, use a razor blade to cut and peel off the thinnest possible layer. Place the layer on a glass slide and use a medicine dropper to add one drop of water to the layer. (Note: It is often possible to obtain a better image by using a drop of water-diluted iodine rather than plain water.) Next, place a cover glass over the glass slide.

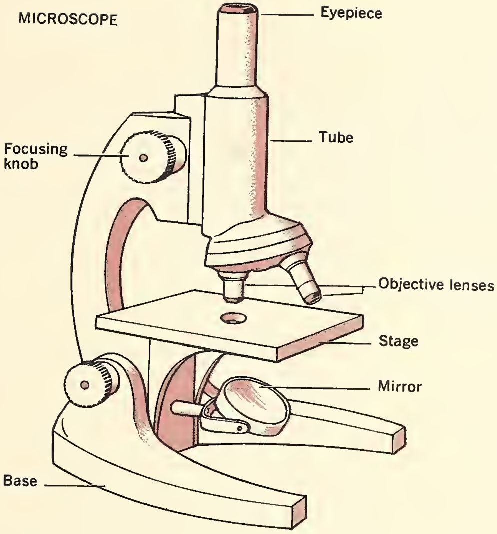
When focusing, place the microscope near a light source such as an open window or a lamp. Adjust the stage so that, when looking through the eyepiece, you see a bright circle of light. Next, with your eye *away* from the eyepiece, slowly turn the focusing knob, lowering the objective lens until it *almost touches* the cover glass. Look again through the eyepiece and slowly turn the focusing knob to *raise* the objective lens. When properly focused, the cells of the onionskin should appear as rectangular, or bricklike, shapes.

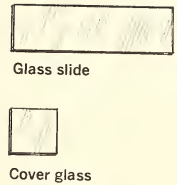
Prepared Microscope Slides

As early as the fourth grade, children should be introduced to the microscope. If possible, they should be shown how to prepare slides of living material such as yeast cells, cheek cells, microorganisms in pond water, and the cells of an elodea leaf.

There are limits to how far children can go in preparing their own slides of living material. At the

MICROSCOPE





time that cells are being studied in science, it is desirable to have available a collection of prepared microscope slides of such subjects as paramecia, spirogyra, molds, bacteria, yeast, roots, stems, leaves, flower parts, human bone, human skin, human muscle, and human blood. These slides can be obtained from any biological supply house. Although they cost about $1.00 a slide, they are permanent slides, and with proper care they can be used for a long time.

A microprojector is an instrument that can be used to project the objects on microscope slides onto a sheet of paper. The projected image is enlarged, and it is thus possible for a number of children to see it at the same time. Even though a microprojector is used, children should also have an opportunity to view the slides through a microscope.

Large Transparencies for Overhead Projectors

The overhead projector is operated from the teacher's desk in the front of the classroom. As the teacher operates the projector, he faces the class and the picture is projected on a screen in back of him. Pictures are prepared on a transparent material and may be either black and white or colored. Their size is about 5 inches by 7 inches. As each picture is to be shown, it is placed upon the stage of the projector, where it is visible to the teacher during the time it is projected on the screen. This makes it possible for the teacher to face the class as he talks and to point out any part of the picture to which he wishes to call particular attention. Transparencies may be obtained from scientific supply houses on a number of

topics related to science. A catalogue of one supply house has listed the following series of transparencies for use in elementary science: Human Body Series, Animal Series, Astronomy Series, Atom Series, Geology Series, Meteorology Series, Electricity Series. The Astronomy Series consists of the Solar System, the Sun, Seasons; the Year, Month, and Day; Time Zones; Solar and Lunar Eclipses; Telescopes; and Satellites. This is an overlay series, which means that there is a set of four transparencies for each topic such as the Solar System. As each transparency in the series of four is laid upon the preceding one, it adds information to the ideas that are to be developed by the set.

"Do-it-yourself" kits are available for those who would like to make their own transparencies. The kits can be used to make diagrams, charts, and graphs. They can be produced in black and white or color. The audiovisual departments in some schools have persons skilled in making transparencies produce transparencies for teachers or teach them how to make their own.

Recordings

Both tape and disk recordings can be obtained on various subjects related to science. Some of the titles are listed below:

DISKS
American Bird Songs (an album of 6 records)
Adventures in Sound and Space
Science of Sound

TAPES
Electricity Goes to Work
Galileo Tests a Theory
Van Leeuwenhoek and the Little Animals
How Men Behave
Scientists at Work
Digging Up the Past
The Ocean and Weather
The Rocket Man
Satellite Story

The National Tape Recording Catalogue, published by the Department of Audiovisual Instruction of the National Education Society, lists more than one hundred titles dealing with topics in science. Many of them, such as the ones previously listed here, are appropriate for use in both elementary and junior high school science classes.

Exhibits

One of the most common uses of exhibits in science teaching is the science fair. Where science fairs are noncompetitive and voluntary, they may have very positive educational value. They encourage children to conduct projects of various kinds in coordination with their work in the science classroom. Children are also encouraged to organize the pertinent ideas into forms that are clearly visible. Imagination, creativity, and resourcefulness are applied in preparing science exhibits. In displaying their exhibits, children gain recognition for their efforts. Furthermore, children learn science from the exhibits prepared by other children. At their level, a science fair may serve much the same purpose that scientific meetings serve for the scientist.

In another section of this Teacher's Guide, the use of museum exhibits in teaching science has been discussed. Some museums prepare small exhibits of different kinds that are loaned to schools. These are prepared in glass-covered boxes for display. Generally, a guide book is sent with the exhibits to help the teacher get the most out of them.

Science museums have become quite popular in some of the larger cities. In these museums the exhibits have been prepared to teach people about scientific discoveries and technological inventions. Before a teacher makes a decision to take his class to a science

museum, he should visit the museum to determine which of the exhibits, if any, are related to topics being studied in his science class. If there are none, he probably should not make the effort to take his pupils.

Industrial firms include exhibits of various kinds among their educational materials. Generally, the exhibits are very attractive but deal rather exclusively with products and/or services in which the industry is primarily interested. Teachers should avoid cluttering up their classrooms with any such exhibits that are not closely related to topics being studied. Exhibits that are given to the school, or those that are pupil-made, often introduce storage problems that teachers find difficult to solve.

Posters of various kinds might be classified as exhibits. They can be used for many different purposes in science. Posters can be made to represent graphically such concepts as the water cycle, the oxygen cycle, interdependence of living things, the law of the lever, the conservation of energy, classification systems, the composition of the earth, electric circuits, and many other scientific concepts.

Models

There are many ways in which models can and should be used in teaching science. Often the use of a model is the only way in which the pupil can "get" the idea that the model represents. The globe of the earth, commonly found in classrooms, is a good example of such a model. It would be extremely difficult to think of the earth as a sphere without such a model. Models of the solar system serve a similar purpose. Models of the human skeleton, the brain, the heart, the eye, the ear, and other parts of the body can be used to help children obtain a better understanding of what the inside of the body is like. Models of atoms and molecules can be used to gain a better understanding of the building blocks of nature.

All the models mentioned above can be obtained from scientific supply houses. On the other hand, children can make many of them. If they do, they will probably come to understand the pertinent concepts better than when they use a commercially made model. In making a model of the solar system, children learn much more about comparative sizes and distances than when merely observing a manufactured one. Similarly, when they construct a model crystal, using toothpicks and wax balls, they come to understand the relative positions of atoms in crystals better than when they observe a prepared model. By using clay, pupils can make models of different kinds of cells, craters on the moon, fossils, the ocean floor, volcanoes, the brain, and molecules. Styrofoam balls of assorted sizes have been used in making models of planets and molecules. Cellophane bags can be used in making three-dimensional models of a typical cell. When given the opportunity, children delight in thinking up ways of making models of the different things they study in science. In the "thinking up" process, they are adding new dimensions to their understanding of the concepts.

CREATING INSTRUCTIONAL MATERIALS

In preparing a science program such as *The Macmillan Science Series,* it is impossible to anticipate every kind of learning situation that will confront the teacher in his day-to-day work. Schools vary from one community to the next. Classes within the school vary, as do the children within a particular class. For these reasons, teachers will find it advantageous from time to time to develop supplementary instructional materials adapted to the unique situations that they encounter in their teaching.

Because of the many ways in which learners may come to understand scientific concepts, the teaching of science provides unusual opportunities for teachers to create dynamic instructional materials. The re-

mainder of this section will include suggestions on how a teacher might begin.

Throughout *The Macmillan Science Series,* demonstrations are written into the text to introduce problems or to reinforce concepts. Additional material is suggested in the TAE. There are other ways, too, beyond those suggested in the TAE whereby concepts and their application can be demonstrated. Here are some questions to think about:

1. What are some ways, other than those given in the text, that can be used to demonstrate that air occupies space?

2. How many ways can you show that vibrating objects produce sound?

3. How many examples can you find of the fact that living things are interdependent?

4. In what situations have you witnessed the concept that once a body is set into motion it continues in a straight-line motion of unchanging velocity until acted upon by an unbalanced outside force?

5. In what other ways can you demonstrate diffusion as an example of the movement of molecules of one substance throughout another?

Questions such as these can be asked about every science concept that is demonstrated in your science text. They can serve as guides to "thinking up" or creating additional demonstrations. The more demonstrations or examples of a concept that can be shown to pupils, the better will be their understanding of it.

Creativity can really bloom when applied to the designing of experiments. Detailed descriptions are given for many experiments in the series. This is done to help pupils learn how the various factors in an experiment are handled. It may be that, for some pupils, more experiments of this type should be given, and it is here that the teacher could profitably spend some time in developing additional ones. In some instances it might be advantageous to modify one of the experiments in the text to include different materials and different experimental situations. For example, in an experiment where bread is used to determine the best conditions for mold growth, a variety of organic materials might be used in addition to bread. After observing the results of one such experiment, pupils frequently give the clue to new experiments by asking the question, "I wonder what would happen if this or that were done?"

The golden opportunity for developing new experiments often comes from something that happens during a science lesson. It may come from a searching question asked by one of the pupils. It may come from an unaccountable observation made by someone in the class. It may come when an experiment does not turn out as the class expected because the hypothesis being tested is not a tenable one. The following are examples of how this has happened in different classes.

In one class the teacher was performing a demonstration to show that soil contains air. As the teacher poured water into a large container of soil, bubbles formed at the surface of the soil. The teacher then asked the question, "What do the bubbles indicate?" As expected, one of the pupils replied. "It shows that there is air in the soil." The teacher followed with the question, "What did you observe that supported such a statement?" The pupil responded, "You could see bubbles which proved that air was coming out of the soil." The teacher then asked the class if they agreed. All but one boy did. He asked, "How do you know that the bubbles were formed by air rather than some other gas?" No one could answer the question, and the class now had a problem. How could you prove that the gas coming from the soil when you poured water into it was air? The teacher, working with a small group of pupils, devised a method for capturing the gas that was given

off when water was poured into the soil. They also devised ways of testing the gas to determine if, in fact, it was air.

In a third grade class the pupils had conducted an experiment to determine how temperature affects the growth of mold on bread. They had kept the moistened pieces of bread in small aluminum pans. As they had expected, considerable mold had developed on the bread that had been kept in a warm place. Little or no mold had developed on the pieces of bread that had been kept in the refrigerator. During the time each pupil was examining the bread mold in the pans, one of the pupils held the pan over his head. As he looked up at the bottom of the pan, he saw several tiny holes in it. He asked the teacher what caused them. The teacher commended him for discovering the holes and then asked the class how they could find out what caused the holes in the pan. This led to a series of very interesting activities, including experimentation and the use of several knowledgeable resource persons. Although the teacher and the children were not able to solve the problem through their own experiments, they learned a great deal about the limitations of their own knowledge and abilities and how to use resource people in solving complex problems. Investigation of the problem showed that carbon dioxide from the mold combined with salt from the bread to form sodium carbonate, which caused the holes to form in the aluminum.

In a fifth grade class the pupils had had a number of experiences in heating objects such as iron wire. They had found that heating the objects caused them to expand. The teacher had encouraged the pupils to give other examples from their own experience. Some mentioned that they had seen pictures of steel rails that had expanded on hot summer days and forced the railroad tracks out of shape. Others told of seeing the same thing happen on concrete highways. One girl in the class said she now knew why the drawers in her dresser became stuck in the summer. She explained that the heat expanded the wood so that the drawers became too tight to move in and out easily. Her explanation seemed reasonable to all members of the class. The teacher asked the class, however, if they were sure that wood expanded when heated. This was a good question, since they had done no experiments with wood. The class accepted the challenge to plan an experiment to test the hypothesis that "wood expands when heated."

In planning a method for testing the hypothesis, the children made many suggestions. With the help of the teacher, each suggestion was examined. Finally this plan was accepted: Three holes were bored into a piece of pine board. Then a length of wooden dowel was cut into three equal pieces. It was found convenient to use a one-inch pine board, to make the holes 3/8 inch in diameter, to get 3/8-inch dowels, and to make each piece four inches long. Each piece of dowel was numbered, and its hole was given the same number.

The first dowel was then put into an oven and heated at 200° F. for an hour. The second dowel was put into the freezing compartment of a refrigerator for an hour. The third dowel, the control, was left in the room.

At the end of the hour, each dowel was again fitted into its hole in the board. The heated dowel did not expand or stick as was expected, but fit more loosely than it had before it was heated. The cold dowel fit more tightly than before. The dowel that had been left in the room fit in the same way as it had before. The children were amazed. Some of them said, "Our experiment didn't work!" The teacher reassured them that the experiment had worked; it just didn't turn out as they had expected. Now the children really had a problem: If heat doesn't cause dresser drawers to stick in the summer, what does?

The teacher followed up by encouraging them to think of other possible reasons. After a while someone

suggested that it might be that high relative humidity on certain days in the summer caused the drawers to stick. How could this hypothesis be tested? Finally someone hit upon the idea of suspending one of the dowels in a covered jar that had water in the bottom of it. It was explained that the air above the water would soon become filled with water vapor, and the relative humidity would be very high. This seemed reasonable to the class, and so they hung one of the dowels above the water in the covered jar. They left it hanging this way until the next day. When they removed the dowel, they found that it had swollen so that they couldn't even force it into its hole.

As you can see, this experiment took several days to complete. Was it worth the time? This question can only be answered "Yes" if you believe that the creative thinking involved in planning an experiment such as this is important in the education of children.

Picture Stories and Other Supplementary Materials

The picture stories beginning with Book 3 have been used to reinforce concepts developed in the texts by showing how these concepts apply in human activities. There are many possibilities for applying the picture story technique to other concepts in local situations. For example, in Grade 1, where the concept of seasonal changes is introduced, a teacher might prepare a collection of snapshots of the class taken during the different seasons of the year. These could then be arranged in a picture story album or bulletin board display. Such a picture story would incorporate the local climatic conditions in ways that are not possible in a single standardized version of the concept of seasonal changes.

The possibilities for picture stories are practically unlimited. Whenever they are prepared, they should deal clearly with an application of one or more science concepts.

Teachers might also find it worthwhile to prepare supplementary materials for introducing certain units in the text. Bulletin board or large poster displays can be prepared, following the format used in the text. If this is done, the displays can be used to facilitate pupil discussion; they should be designed to help pupils understand better what the unit is about and to make more clear the purposes for studying it.

There may be local situations that relate in unique ways to certain of the units. Where this is so, supplementary materials can be prepared to show the relationship. For example, in communities near the ocean, the unit on oceanography (Book 5) would be introduced quite differently than it would be in communities far removed from the ocean. Because of the climatic differences among communities, units having to do with weather might be introduced in different ways. The unit on conservation (Book 6) would be introduced differently in urban communities than in rural communities. Thus, before undertaking any unit in science, the teacher should investigate possible ways of introducing it so that it relates most closely to the unique experiences of the pupils. When this is done, it will often lead to the development of unit introductory materials to supplement those in the text.

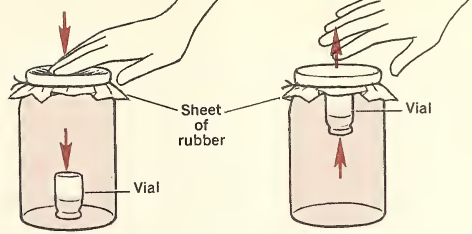
Reviews

One of the many strengths of *Science for Tomorrow's World* is the way in which units are reviewed. Review sections occur frequently and in a variety of interesting forms throughout each book. There are several phases involved in a review of concepts. One phase has to do with *recall* of the facts related to the concepts developed. A second has to do with *relating* the facts to the pertinent concepts. A third has to do with *applying the concept* or using it to explain something. A fourth has to do with using the concept to *predict* what will happen under certain conditions to which the concept applies. In other words, good re-

views provide for practice in identification, interpretation, application, and prediction. Since there are numerous commonly used ways of providing practice with each of these, the creating of new ways is an exciting challenge to any teacher.

Good reviews include the skills and attitudes involved in scientific inquiry. There are several ways of reviewing the skills involved in the planning of an experiment. One way is to present a problem which can be answered by experimentation and to then ask the pupils to plan the experiment. They might do this individually and then write up their plans. They might work in groups of four or five, and each group could then present its plan to the entire class. Or the entire class, with one of the pupils as the leader, might work up the plan. In the latter two instances, all pupils have the opportunity to take part in the evaluation of the planning. Reviews of this sort will be more effective if the teacher gives the students a novel problem—one that is not like any they have worked on before. Another way to provide for review of skills involved in experimentation is to keep a close record of an experiment, noting all pertinent details, including the results and the conclusions. Some of the common errors in experimentation should then be introduced into the record. Give the pupils the experiment as it is written, and ask each of them to evaluate it.

There are many ways in which skill in observation can be practiced through reviews. Demonstrations might be performed and pupils asked to record their observations. Where this is done, the demonstration must call for rather careful observation. One such activity might be the cartesian diver. One cartesian diver demonstration calls for a flat bottle filled with water and covered with rubber sheeting (see diagram). Suspended in the water is an inverted vial that is nearly filled with water. As the rubber sheeting is pressed, the vial goes down. As the pressure is released, the vial rises. The class is asked to tell why the vial went down and then up. The system under observation con-



sists of bottle, water, vial, and hands. Those who have never seen the demonstration before must observe quite carefully to be able to tell that the vial goes down when the hands are pressing the rubber sheeting and that it comes up when the pressure is removed. There are many other demonstrations like this one that teachers could develop and use to give practice in observing.

Here is another example, which has to do with two scientific attitudes—objectivity in evaluating evidence, and reluctance to make a judgment until conclusive evidence has been accumulated. An investigation can be described in which data of both sound and dubious quality are reported. Based upon the evidence, certain conclusions are drawn. Some of the conclusions are consistent with the data, and some go beyond the data. After pupils have read the investigation, they are asked to evaluate the conclusions. What they react to in their evaluations should indicate whether they are weighing evidence and suspending judgment.

In this section we have seen that there are good reasons for teachers to create instructional materials. Through the process, teachers are providing for one of their basic needs, the need to be creative. Consequently, they gain greater satisfaction from their teaching. But more important are the values that come to the pupils who use the materials that the teachers prepare. The learning idiosyncrasies of pupils will be more nearly met, and their relative achievement in learning the concepts and using the methods of scientific inquiry will be improved.

OVERVIEWS OF UNITS IN BOOK 6

This section provides a brief overview of each unit in the book. At the end of the section you will find a listing of the table of contents of each book. This overall table of contents will give you an opportunity to visualize the total program of *Science for Tomorrow's World* and to see the interrelationships of subject matter in the conceptual organization of the series.

Unit One: The Scientist's Way—Measuring Things

If there is one characteristic of science that is fundamental, it is insistence on accurate measurement. Today's science is based on measurements of length, time, and mass that are accurate and repeatable. Because of its importance, and because of its rather elementary nature, measurement is the subject of this first unit. The unit begins with a discussion of standards of measurement and the special importance of the metric system in science. The fundamental constants — mass, length, and time—are discussed, and the pupil is shown how simple combinations of length and time can be built up into secondary standards such as velocity and acceleration. Graphs are an invaluable aid to the understanding of how measured values change with changes in time, and this unit explains how simple graphs are made and how these graphs can be used to measure the motion of objects. Building on the concepts of motion already developed in the preceding pages and in the previous books, vectors are introduced. By the conclusion of this unit, the pupil has learned the concepts necessary for the development of concepts introduced in succeeding units.

Unit Two: Heat and Molecules

In this unit we are concerned with a part of the physical world studied by physicists. Man's study and interpretation of the universe are centered around two basic concepts: *matter* and *energy*. Everything in our physical universe is one or the other.

Heat is easily recognized as a form of energy, along with light, sound, electricity, and all radiations. These all perform or do work under certain conditions. In other words, they can cause matter to move.

Heat is closely associated with the motions and other energies of particles of matter such as atoms and molecules. Thus the study of heat and the study of particles of matter are complementary.

To understand what happens when a body absorbs or emits heat energy, we must have an idea of the structure of matter itself.

There is a mass of convincing evidence that all matter consists of tiny individual particles that are in constant motion and separated from one another by space. These small particles and the atoms, molecules, and ions they constitute attract each other at close distances and band together to form the gases, liquids, and solids of our daily experience.

Heating a substance to higher temperatures increases molecular motion until, at high temperatures, the fast-moving molecules become fully separated from each other and the substance is in a gaseous state. At low temperatures the motions are reduced and the attractions of the molecules themselves take over, leading the substance to form a solid.

The concept of molecules is further developed in the section *How Do Objects Become Heated?* Various common phenomena with which the pupils are familiar are introduced—conduction through metals, radiation through space, and the expansion and contraction of metallic substances. The pupil is made to realize that all of these phenomena are simply explained by postulating the existence of molecules.

Unit Three: Objects in Motion

The concept of motion was introduced in Unit 1 through a discussion of units of measurement; the motion of molecules was discussed in Unit 2 to explain the phenomena associated with the three states of matter and with changes in temperature. This unit discusses the forces that produce motion in the first place. Newton's Laws of Motion are introduced and discussed in detail. In particular, the pupils are shown how a constant force can result in an accelerated motion. The forces that resist any increase in acceleration are also discussed. Having assimilated the concepts of inertia, momentum, and acceleration, the pupils are introduced to gravitational force. Gravity affects all objects traveling freely in space and changes theoretically straight-line motion into parabolic paths. The pupils learn how the actual paths followed by objects moving through space are the result of their momentum and of gravitational attraction. The unit makes use of the interest in space flight to show how the orbit followed by a space capsule or satellite is the result of a balance of forces. The forward momentum of the capsule just balances the downward attraction of gravity, enabling the capsule to continue "falling" to the earth in a constant circuit. The unit concludes by showing how the same principles can be applied to other objects orbiting the earth and the sun.

Unit Four: Electricity and Electronics

The phenomena of electricity and magnetism have been known from the time of early Greek civilization and probably before. Only recently have the relationships connecting them been exposed.

Even today we do not have a full explanation of electricity or magnetism, but we do have strong evidence to support the belief that they are related phenomena. We also have strong evidence for a theory that explains the very structure of matter in terms of electricity.

Underlying this unit is a concept that should be brought frequently to the pupils' attention: *All matter is electrical in nature, and the study of electricity, magnetism, and electronics is simply a study of one aspect of this electrical structure.* It is the study of moving electric particles.

Because electricity (electrons in motion) is a phenomenon involving charged particles, *atomic structrure* is used to explain some ideas concerning those particles found free in nature and also as parts of a balanced atom. Understanding of electricity requires an understanding of the simplest atomic model.

The models (analogs) used to explain atomic structure and behavior must be thought of only as models. The model used in this book is a simplified version of what is known as the Bohr model. As the pupils progress through high school and college, this model will give way to more complete and exact models.

Today, scientists recognize three fundamental forces in nature: *electromagnetic, gravitational,* and *nuclear*. Outside the nucleus of an atom, all forces reduce to electromagnetic and gravitational forces. This concept is a unifying one.

Unit Five: Astronomy

In this unit the pupils examine how scientists build models to explain the behavior of objects that they cannot examine directly. In this case, the objects are the planets of the solar system, and the models are designed to explain the behavior (i.e., the motions) of the planets. These two models are the Ptolematic and the Copernican theories of planetary motion. If the motions of the planets are recorded without the aid of telescopes or other instruments, it is impossible to choose between Ptolemy and Copernicus. Their explanations are equally correct. In the course of investigating the behavior of the planets and attempting to decide the merits of the two models, the pupils learn how the planets move, including the apparent retrograde motions of Mars and Venus, and how, by the use of triangles, the distances of nearby stars can be measured. The pathfinder is A. C. Bernard Lovell, who invented the radio telescope. This unit concludes with a discussion of the Milky Way and other galaxies.

Unit Six: The Nature of Light

In this unit, two ways of thinking about light are presented: the particle theory and the wave theory. Each is useful in explaining certain behaviors of light. By developing the theory of light through these theories, you will help pupils think about the behaviors of light as the scientist does.

The text offers many activities based on these theories that are simple and call for equipment that is readily available. The activities are designed to help the pupil build mental images of the concepts being taught. The terms *reflection, refraction,* and *diffraction* present little difficulty to the pupil whose mental images of these behaviors of light are based on the theoretical models in this unit. These mental images, formed from concrete experiences, provide the foundation for more difficult concepts to be learned later.

Unit Seven: Life on the Earth

The pupil from his past learnings is guided to the major concept that life on the earth is ultimately dependent on the sun. The earth's position in relation to the sun and its distance from the sun make the type of life that we know possible. The energy needed to maintain terrestrial life is also obtained from the sun.

All living cells, whether in a tree, a blade of grass, an elephant, or man, obtain their energy from oxidizable fuels which we call foods. Oxidizable fuels are those that can be burned, or combined with oxygen. The basic food substance, found in almost every living cell, is a simple sugar called *glu*cose. In plants, this substance is made by the energy of the sun operating directly on the chemistry of a living green cell.

When a green plant grows in sunlight, it is really trapping solar energy. Since man's food comes from animals that eat green plant products or from plant life directly, man is also dependent on solar energy.

The concept that all animal life is dependent on the green plant, which is the major link between animals and the energy of the sun, is the major concept developed in this unit.

Unit Eight: How Animals Behave

One of the most fundamental characteristics of living things is *irritability*, or *responsiveness*—that is, the ability to react to the environment. Since animal life is more complex than plant life, we would expect the reactions of animals to environmental changes to be more complex and varied than those of plants.

Adaptations of various organisms studied in Unit 7 are modes of behavior for survival. In a sense, most forms of behavior have as an end product the survival of the organism. In this unit animal behavior is studied primarily as the reaction and adaptation of an individual to single stimuli.

The section of the last unit on conservation shows how man's well-being is dependent on the balance

of nature and on the well-being of all life on the planet.

Behavioral studies attempt to answer such questions as:

To what stimuli do living things respond? They respond to chemicals (including food), physical contact, gravity, temperature and heat, light, sound, motion, and radiation.

How do they respond? They respond by movement, secretion, growth, temperature change, luminescence, and producing electricity.

What structures and organs are involved in detecting stimuli? Stimuli are detected by so-called sense organs or receptors, from one-celled and subcellular organelles to complex organs such as the human ear.

What structures and organs are involved in responses to stimuli? The structures range from organelles to the entire organism.

What communication systems connect messages from receptors to respondors? Nervous systems, in complex organisms, serve this function.

What are the conditions that permit an organism to learn new responses?

What is learning?

What is intelligent behavior?

How much behavior is learned as an individual and how much is inherited?

The pupil is brought to realize that responses to the last four questions approach the limits of man's knowledge, and that there is a vast amount of knowledge still to be gleaned from behavioral studies.

About 12,000 years ago, in the Neolithic revolution, man shifted from food collecting to food producing and developed agricultural pursuits. It was then that man began the process of changing his community by clearing unwanted vegetation and replacing it with food crops.

Further change came about 5,000 years ago in the "urban revolution." The change was the discovery of methods of storing and transporting foods and materials to urban centers. Trade and organization developed, and towns grew to cities and cities to empires. Population increased. The "industrial revolution" emerged 100 years ago.

We are now in the stages of a great scientific revolution, one that is based on the genius of Galileo, Newton, Faraday, and Pasteur. The fantasies of yesterday are today's realities.

This unit introduces the pupil to the new frontiers of expanding knowledge in the sciences. Bionics, biopower, cryogenics, lasers, and ultrasonics are areas in which there will be dramatic developments in the youngsters' lifetime. All of these fields and other important areas of research offer many career opportunities for the science-minded pupil. Perhaps more importantly, for those who will not enter scientific fields, this unit reinforces the concept that man has changed and continues to change his environment. Our lives today and tomorrow are immeasurbly affected by the developments in science.

SCIENCE FOR TOMORROW'S WORLD: BOOKS 1-6

TABLE OF CONTENTS

TESTS FOR SCIENCE FOR TOMORROW'S WORLD

On the following pages you will find tests for each unit in the book and for the two "Do You Remember?" sections. The Macmillan Company authorizes any teacher using *Science for Tomorrow's World,* Books 1–6, to reproduce *for use in his* or *her classroom only* the tests in this guide.

Unit 1: *The Scientist's Way—Measuring Things*

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. Scientists use the — 1. **b**
    a. English system
    b. metric system
    c. German system

2. The prefix "milli" means — 2. **a**
    a. $\frac{1}{1000}$
    b. $\frac{1}{100}$
    c. $\frac{1}{10}$

3. One meter is equal to — 3. **c**
    a. 37.97 inches
    b. 38.23 inches
    c. 39.37 inches

4. The standard unit of mass in the metric system is the — 4. **b**
    a. ounce
    b. gram
    c. pound

5. Degrees Centigrade are used to measure — 5. **b**
    a. weight
    b. temperature
    c. mass

6. A kilometer equals — 6. **b**
    a. 100 meters
    b. 1,000 meters
    c. 10,000 meters

7. When a piece of metal is warmed, the volume of the metal — 7. **b**
    a. remains the same
    b. increases
    c. decreases

8. The mass of an automobile driven from the seashore to the top of a mountain
   a. remains the same
   b. increases
   c. decreases

8. a ___ ___ ___ ___ ___

9. An inch is equal to
   a. 2.54 centimeters
   b. 1 centimeter
   c. 100 centimeters

9. a ___ ___ ___ ___ ___

10. As an elephant walks toward the top of a mountain, its weight will
   a. decrease
   b. increase
   c. remain the same

10. a ___ ___ ___ ___ ___

11. If Jim's father needed 3 hours to drive directly from his home to a city 120 miles away, he was driving at a speed of
   a. 60 miles per hour
   b. 40 miles per hour
   c. 30 miles per hour

11. b ___ ___ ___ ___ ___

12. The formula for an airplane's flight time is
   a. speed $\times$ distance
   b. $\frac{\text{distance}}{\text{speed}}$
   c. $\frac{\text{speed}}{\text{distance}}$

12. b ___ ___ ___ ___ ___

13. Sonar is an instrument used to measure
   a. the speed of sound
   b. distances under water
   c. temperatures under water

13. b ___ ___ ___ ___ ___

14. When a piece of copper is heated, it
   a. gains weight
   b. loses weight
   c. does not change weight

14. a ___ ___ ___ ___ ___

15. When a log burns, it
   a. releases oxygen
   b. takes some oxygen from the air
   c. loses weight

15. b ___ ___ ___ ___ ___

16. The planet Uranus was discovered by
    a. Galileo
    b. Herschel
    c. Leverrier

16. **b**

17. Oxygen was named by
    a. Lavoisier
    b. Bessel
    c. Herschel

17. **a**

18. Rangefinders are used to measure
    a. the speed of light
    b. the speed of sound
    c. distances

18. **c**

19. A velocity vector indicates the
    a. speed of a moving object
    b. speed and direction of a moving object
    c. direction of a moving object

19. **b**

20. If an automobile moves eastward at a constant speed of 50 m.p.h.,
    a. the velocity of its wheels does not change
    b. the velocity of a point on one of its tires keeps changing
    c. the speed of its wheels is constantly changing

20. **b**

Fill in the correct word or words for each sentence.

volume   velocity   mass   standard units   parallax

1. **Standard units** are units that everyone agrees to use.

2. **Mass** is the quantity of matter in an object.

3. **Volume** is the amount of space that something occupies.

4. The speed at which an object travels in a certain direction is called its **velocity.**

5. The apparent shift in position of an object when it is looked at from two different locations is called **parallax.**

Unit 2: Heat and Molecules

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. All matter is in one of — 1. b
   a. 2 states
   b. 3 states
   c. 4 states

2. The smallest particle of a substance that has all the characteristics of that substance is — 2. b
   a. an atom
   b. a molecule
   c. a diffusion

3. The molecules in a gas move — 3. a
   a. more rapidly than do the molecules in a solid
   b. less rapidly than do the molecules in a solid
   c. at the same speed as do the molecules in a solid

4. The molecules in a glass of milk — 4. c
   a. are in a fixed position
   b. seldom move
   c. are constantly in motion

5. If a gas stove leaks, then all of the escaping gas will — 5. c
   a. stay around the stove
   b. rise above the stove to the ceiling
   c. diffuse throughout the kitchen

6. The molecules in a bowl of warm soup will move — 6. b
   a. more slowly than the molecules in a glass of iced tea
   b. more rapidly than the molecules in a glass of iced tea
   c. less rapidly than the molecules in an ice cube

7. If you place ice around a jar of warm water, the water molecules will — 7. b
   a. move about more rapidly
   b. move about less rapidly
   c. continue to move about at the same speed

8. If a rifle is fired rapidly many times, the barrel becomes warm — 8. c
   a. because of the presence of caloric
   b. because the molecules in the rifle barrel become more fixed in their positions
   c. because of the friction produced by the bullets passing through the barrel

9. If a gas is heated, the molecules in the gas will move — 9. c
   a. slower than they did before
   b. at the same speed as they did before
   c. faster than they did before

10. If you take a marble from your pocket and drop it into a glass of ice water, the marble will then — 10. b
   a. expand
   b. contract
   c. remain exactly the same size

11. The Latin word "centi" means — 11. a
   a. 100
   b. 10
   c. 1,000

12. On a Centigrade scale, the freezing point of water is — 12. a
   a. 0°
   b. 32°
   c. 10°

13. On a Fahrenheit scale, the boiling point of water is — 13. b
   a. 100°
   b. 212°
   c. 200°

14. Chemists usually use — 14. a
   a. the Centigrade scale
   b. the Fahrenheit scale
   c. another type of scale

15. Temperature is a measurement of the — 15. c
   a. size of molecules
   b. number of molecules in a substance
   c. average speed of the molecules in a substance

16. An electric heater will warm a room by
    a. radiation
    b. friction
    c. conduction

16. a

17. Count Rumford did experiments involving
    a. diffusion
    b. conduction
    c. friction

17. c

18. The molecules of a substance
    a. all move at the same speed
    b. are usually in a rigid or fixed position
    c. move at different speeds

18. c

19. If you hold an ice cube and rub it across the top of a table, increasing the speed of your hand,
    a. the rate at which the ice cube melts will not change as a result of the increased movement
    b. the ice cube will get colder
    c. the ice cube will then melt faster with the increased speed of your hand

19. c

20. A bathtub full of hot water for bathing
    a. contains more heat than a boiling coffeepot
    b. contains less heat than a boiling coffeepot
    c. has a higher temperature than a boiling coffeepot

20. a

Fill in the correct word for each sentence.

conduction contraction molecules diffusion radiation

1. The process by which molecules move from an area where there are many to an area where there are fewer is called **diffusion.**

2. **Conduction** occurs when objects of two different temperatures touch each other.

3. **Radiation** is the giving off of heat, light, or other kinds of energy by the source of the energy.

4. **Contraction** is caused by the lesser activity of molecules whose temperature is reduced.

5. The heat of an object is produced by the motion of its **molecules**.

Unit 3: Objects in Motion

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. The resistance of two surfaces sliding over one another is called — 1. **b**
   a. refraction
   b. friction
   c. acceleration

2. When the forces acting on an object are equal in size and come from opposite directions, the object will — 2. **c**
   a. move to the right
   b. move to the left
   c. remain at rest

3. If you roll a ball across a level surface, the ball will gradually slow down and then stop because of — 3. **a**
   a. frictional forces
   b. acceleration
   c. escape velocity

4. Constant speed of objects means that — 4. **a**
   a. an object moves the same distance during the first second as during the second, the same distance during the second second as during the third, and so on
   b. an object moves at an increased rate as each second passes
   c. all objects dropped from the top of the same high building will fall at the same speed

5. If no outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed. This concept was first stated by — 5. **a**
   a. Isaac Newton
   b. Galileo
   c. Aristotle

6. To start an object moving, the balance of forces
   a. must be the same
   b. must be upset
   c. must be kept constant

6. b

7. If you double the force on a mass that is moving, the acceleration
   a. triples
   b. remains the same
   c. doubles

7. c

8. The point on an orbit closest to the earth is called the
   a. apogee
   b. vector
   c. perigee

8. c

9. An object will orbit the earth if the object is accelerated
   a. to a horizontal speed of 100 miles per hour
   b. to a vertical speed of 60 miles per hour
   c. to a horizontal speed of 5 miles per second

9. c

10. Forces represented by arrows are
    a. diffusion
    b. vectors
    c. conduction

10. b

11. The mathematical relationship of force, mass, and acceleration is called
    a. Newton's Fourth Law of Motion
    b. Newton's Law of Action-Reaction
    c. Newton's Second Law of Motion

11. c

12. All objects in the universe appear to follow
    a. the same laws of motion
    b. different laws of motion
    c. no special pattern of motion

12. a

13. The moon orbits the earth in about
    a. 9 days
    b. 27 days
    c. 31 days

13. b

14. Comets
    a. are never more than a mile in diameter
    b. are very few in number
    c. have very little mass compared to the planets

14. c

15. Newton's Law of Gravitation and Laws of Motion appeared in
    a. *Principia*
    b. *Theories of Motion*
    c. *Gravitation*

15. a _ _ _ _ _

16. The planet in our solar system that has an orbit different from the orbit of the earth and the orbits of other planets is
    a. Mars
    b. Jupiter
    c. Pluto

16. c _ _ _ _ _

17. Gravitational force between the earth and moon is explained by
    a. Newton's Law of Universal Gravitation
    b. Galileo's First Law of Motion
    c. Aristotle's Theory of Time Intervals

17. a _ _ _ _ _

18. In its solar orbit, Earth moves at an average speed of about
    a. 40 miles per hour
    b. 60 miles per second
    c. 18 miles per second

18. c _ _ _ _ _

19. When velocity of an object increases, the object is said to
    a. accelerate
    b. protract
    c. decelerate

19. a _ _ _ _ _

20. If you push a shoe faster and faster across the room, the friction
    a. increases
    b. decreases
    c. remains the same

20. a _ _ _ _ _

Fill in the correct word or words for each sentence.

ellipse perigee apogee horizontal force gravitational force

1. The point on an orbit nearest the earth is the **perigee.**

2. Most orbits of bodies in space are in the shape of an **ellipse.**

3. The point on an orbit farthest from the earth is the **apogee.**

4. The **gravitational force** between the earth and the moon is just enough to keep the moon in orbit around the earth.

5. After an object is shot straight up to clear the earth's atmosphere, a **horizontal force** is applied to put the object in orbit.

Unit 4: *Electricity and Electronics*

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. The smallest particle of matter that is identifiable as an element is — 1. **b**
   a. an electron
   b. an atom
   c. a nucleus
2. Joseph J. Thomson found that particles that made up cathode rays — 2. **c**
   a. did not travel in straight lines
   b. did not have weight
   c. were made up of moving particles of matter
3. All electrons — 3. **b**
   a. are not identical
   b. repel each other
   c. attract each other
4. Protons — 4. **a**
   a. carry an elementary charge of positive electricity
   b. carry an elementary charge of negative electricity
   c. do not possess gravitational mass
5. Atoms — 5. **c**
   a. usually contain different quantities of positive and negative electricity
   b. of one element are usually very similar to atoms of another element
   c. are usually neutral
6. Electrons can easily flow through — 6. **a**
   a. iron
   b. an insulator
   c. glass

7. Copper is a good conductor because
   a. the copper atom rarely loses an electron
   b. the copper atoms have many free electrons
   c. the copper atom contains more electrons than protons

7. **b**

8. A dry cell battery generates electrical energy
   a. from moving magnetic fields
   b. through chemical action
   c. from friction

8. **b**

9. The vibration of particles of matter
   a. does not produce heat
   b. produces thermal energy
   c. produces gravitational mass

9. **b**

10. If a bar magnet is heated,
    a. the atoms will all point in the same direction
    b. it may become demagnetized
    c. its magnetic field will increase in strength

10. **b**

11. A piece of soft iron
    a. will hold its magnetism for a very long time
    b. is composed of atoms held in rigid positions
    c. will lose its magnetism faster than a magnet made of very hard steel.

11. **c**

12. Computers are helpful to scientists because
    a. they never make a mistake
    b. they are able to work five times faster than a mathematician working alone
    c. they are capable of solving mathematical problems that would require the lifetime of a skilled mathematician to solve

12. **c**

13. A compass needle has
    a. two negative poles
    b. a north pole
    c. three poles

13. **b**

14. A neutron has
    a. a positive charge
    b. a negative charge
    c. no electrical charge

14. **c**

15. Air
   a. is a good conductor
   b. is an insulator
   c. has many more free electrons than iron

15. b _ _ _ _ _

16. The strong tendency of electrons to move away from the nucleus of the atom is called
   a. inertia
   b. thermal energy
   c. gravitational mass

16. a _ _ _ _ _

17. A galvanometer measures
   a. electric current
   b. heat
   c. the intensity of light

17. a _ _ _ _ _

18. The atoms of matter making up insulators
   a. have many free electrons
   b. usually have a negative charge
   c. hold on to all their electrons

18. c _ _ _ _ _

19. An electric current flowing through a conductor produces
   a. a magnetic field
   b. inertia
   c. no effect on a compass placed under the conductor

19. a _ _ _ _ _

20. If one end of a piece of copper wire is attached to one binding post of a dry cell battery and the other end of the wire is attached to the other binding post,
   a. the wire will act as an insulator
   b. the battery will be ruined if the wire is left in this position for a long time
   c. neutrons will flow through the wire

20. b _ _ _ _ _

Fill in the correct word or words for each sentence.

electric current   accelerators   energy   cathode rays

elementary particles

1. **Energy** is the ability to move something by pushing or pulling.

2. Joseph Thomson said that **cathode rays** are particles of negative electricity that come from within the atom.

3. Electrons and protons are called **elementary particles.**

4. Man can produce certain elements in machines called **accelerators.**

5. Electrons moving through a conductor are called an **electric current.**

Unit 5: Astronomy

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. Nicolaus Copernicus published a book that — 1. **c**
   a. explained for the first time that the sun, not the earth, is the center of the universe
   b. explained what stars are made of and how they are born
   c. explained that the sun is the center of the solar system

2. The Ptolemaic model of the earth is — 2. **b**
   a. a sun-centered model of the solar system
   b. an earth-centered model of the solar system
   c. a moon-centered model of the solar system

3. Retrograde motion is — 3. **a**
   a. the backward motion of an object that is moving forward
   b. the increase in speed of a moving object
   c. the tendency of motionless objects to remain motionless

4. The word "planets" means — 4. **c**
   a. searching
   b. revolving
   c. wandering

5. Ptolemy believed that each planet went around the earth in two circles; the smaller circle was called an — 5. **a**
   a. epicycle
   b. apogee
   c. perigee

6. Ideas that explain how or why things happen as they do are called
   a. models
   b. guesses
   c. problems

6. a _ _ _ _ _

7. The apparent shift of an object viewed from two points is called
   a. parallax
   b. parallel
   c. perigee

7. a _ _ _ _ _

8. The distance from the earth to the sun is about
   a. 3,670,000 miles
   b. 36,000,000 miles
   c. 93,000,000 miles

8. c _ _ _ _ _

9. The planets orbit the sun in
   a. a counterclockwise direction
   b. a clockwise direction
   c. both counterclockwise and clockwise directions

9. a _ _ _ _ _

10. Mercury, the planet closest to the sun, travels around the sun in
    a. 365 days
    b. 88 days
    c. 215 days

10. b _ _ _ _ _

11. A large group of stars is called a
    a. nebulae
    b. solar system
    c. galaxy

11. c _ _ _ _ _

12. An English scientist, Bernard Lovell, developed the
    a. radio
    b. radio telescope
    c. radio microscope

12. b _ _ _ _ _

13. The earth is in the galaxy known as
    a. Andromeda
    b. Orion
    c. Milky Way

13. c _ _ _ _ _

14. In our galaxy, each star
    a. has its own orbit around the center of the galaxy
    b. orbits at the same speed around the center of the galaxy
    c. moves rapidly in triangular orbits

14. a _ _ _ _ _

15. "Nebulae" is the Latin word for
    a. clouds
    b. dust
    c. gas

15. a _ _ _ _ _

16. Planets close to the sun move
    a. more slowly
    b. more rapidly
    c. at the same rate

16. b _ _ _ _ _

17. On a clear night, you are able to see
    a. only the stars in our own galaxy
    b. hundreds of other galaxies
    c. stars in about 10 other galaxies

17. a _ _ _ _ _

18. Scientists think that there are
    a. billions of galaxies in our solar system
    b. several thousand galaxies in the universe
    c. billions of galaxies in the universe

18. c _ _ _ _ _

19. The straight distance through the center from one side of a round object to the other side is called the
    a. radius
    b. diameter
    c. protractor

19. b _ _ _ _ _

20. The light that you see from the stars tonight left those stars
    a. last night
    b. last week
    c. over two thousand million years ago

20. c _ _ _ _ _

Fill in the correct word for each sentence.

triangles protractor galaxy Earth light-year

1. The degrees in an angle are measured with a **protractor.**
2. Size and distance may be measured by using similar **triangles.**
3. The distance light travels in one year is called a **light-year.**
4. Our sun is only one star in a large group of stars called a **galaxy.**
5. **Earth** travels around the sun in about 365 days.

Unit 6: *The Nature of Light*

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. Light — 1. **b**
    a. cannot travel through empty space
    b. is made up of tiny particles
    c. depends on something through which to travel

2. Light travels — 2. **c**
    a. 100,000 miles per second
    b. 200,000 miles per hour
    c. 186,000 miles per second

3. The scientist who first measured speed of light precisely was — 3. **a**
    a. Albert Michelson
    b. Joseph Thomson
    c. Rachel Carson

4. When a person looks at an object, the image is formed on the — 4. **b**
    a. pupil of the eye
    b. retina of the eye
    c. back of the eyelid

5. The angle at which a light particle bounces off a surface is — 5. **b**
    a. less than the angle at which the particle of light hits the surface
    b. equal to the angle at which it hits the surface
    c. greater than the angle at which it hits the surface

6. Light travels fastest in — 6. **c**
    a. water
    b. air
    c. empty space

7. When light travels through different substances it — 7. **b**
    a. maintains a constant speed
    b. changes speed
    c. always decreases its speed

8. If a line is drawn perpendicular to the surface of water where light strikes the surface, the line is called the — 8. a
   a. normal
   b. refraction
   c. diffraction

9. The bending of light as it enters a different substance is called — 9. b
   a. diffraction
   b. refraction
   c. reflection

10. When light moves from air to water, it — 10. a
    a. bends toward the normal
    b. bends away from the normal
    c. continues to travel at the same speed

11. Fast-moving particles of light bend — 11. b
    a. more than slow-moving ones
    b. less than slow-moving ones
    c. the same amount as slow-moving ones

12. Light would refract less when going from air through — 12. c
    a. a glass of water
    b. a glass of iced tea
    c. a jar with almost no air in it

13. The bending of light as it passes a sharp edge is called — 13. b
    a. refraction
    b. diffraction
    c. reflection

14. The low point of a wave is called the — 14. b
    a. crest
    b. trough
    c. wavelength

15. In the pinhole camera, light forms — 15. a
    a. an upside-down image
    b. a right-side-up image
    c. no image at all

16. Light waves
    a. cannot pass through each other
    b. must travel through air
    c. can pass through each other

16. **c**

17. In diffraction, the light passing a sharp edge
    a. bends to form an angle
    b. bends in the shape of a gentle curve
    c. ceases to act as little packets of energy

17. **a**

18. The substance in which a wave travels
    a. moves along with the wave
    b. does not move along with the wave
    c. does not affect the speed of the wave

18. **b**

19. The nature of light is best explained by
    a. the particle theory
    b. the wave theory
    c. a combination of both theories

19. **c**

20. Isaac Newton developed the
    a. wave theory of light
    b. particle theory of light
    c. packets of energy theory

20. **b**

Fill in the correct word for each sentence.

light-year reflected diffraction refraction corpuscles

1. Isaac Newton, when referring to particles of light, used the word **corpuscles.**

2. A **light-year** is the unit of measurement that scientists use to measure distances in the universe.

3. When light particles strike an object, scientists say that the particles are **reflected.**

4. The bending of light as the light passes a sharp edge is given the name **diffraction.**

5. The bending of light when it enters a different substance is called **refraction.**

Do You Remember?—Units 1, 2, 3, 4, 5, 6

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. In the metric system, the gram — 1. **b**
   a. is a unit of temperature
   b. is the standard unit of mass
   c. is used to measure distance
2. The amount of space that something occupies is its — 2. **a**
   a. volume
   b. weight
   c. force
3. The amount of matter in an object is called its — 3. **c**
   a. weight
   b. height
   c. mass
4. Your weight — 4. **a**
   a. changes according to how high you are above sea level
   b. does not change as long as you do not travel in space
   c. is the same as your mass
5. Sonar is an instrument used to — 5. **a**
   a. locate objects under water by reflected sound waves
   b. measure temperatures under water
   c. measure radiation
6. The speed at which an object travels in a certain direction is called — 6. **c**
   a. a diffusion
   b. its relative humidity
   c. its velocity
7. When charcoal burns, it — 7. **a**
   a. takes some oxygen from the air
   b. releases oxygen
   c. increases its mass
8. A statement of relationship among units of measurement is called — 8. **c**
   a. volume
   b. a vector
   c. a formula

9. The smallest particle of matter that can be identified as an element is
   a. a proton
   b. an atom
   c. a molecule

   9. b

10. The movement of molecules away from a crowded area to a less crowded area is called
    a. conduction
    b. radiation
    c. diffusion

    10. c

11. Temperature is a measurement of
    a. the number of atoms in a substance
    b. the average speed of the molecules in a substance
    c. the size of molecules

    11. b

12. An object accelerates when
    a. the velocity of the object increases
    b. it rubs against another object
    c. the velocity of the object decreases

    12. a

13. The point on an orbit farthest from the earth is the
    a. perigee
    b. apogee
    c. vector

    13. b

14. The strong tendency of electrons to move away from the nucleus is called
    a. friction
    b. escape velocity
    c. inertia

    14. c

15. The Copernican model of the universe was
    a. an earth-centered model of the solar system
    b. a sun-centered model of the solar system
    c. a moon-centered model of the solar system

    15. b

16. The unit of measurement used to measure distances to the stars is the
    a. millimeter
    b. light-year
    c. centimeter

    16. b

17. A large group of stars is called a
    a. solar system
    b. epicycle
    c. galaxy

    17. c

18. The bending of light as it passes a sharp edge is called
    a. diffraction
    b. reflection
    c. refraction

18. a

19. Light travels
    a. 100,000 miles per second
    b. 50,000 miles per second
    c. 186,000 miles per second

19. c

20. The wave theory of light states that
    a. light consists of tiny particles of matter that scientists refer to as corpuscles
    b. light consists of waves that travel from the source of the light
    c. light waves always travel at the same speed when they go through different materials

20. b

21. The bending of light as it enters a different substance is a process that scientists call
    a. reflection
    b. refraction
    c. diffraction

21. b

22. The most satisfactory explanation of the nature of light is
    a. the particle theory
    b. the wave theory
    c. a combination of botn theories

22. c

23. Light travels
    a. at the same speed in different substances
    b. fastest in empty spaces
    c. faster in water than in air

23. b

24. Electrons
    a. carry an elementary charge of positive electricity
    b. carry an elementary charge of negative electricity
    c. do not possess any electric charge

24. b

25. When water is heated, the molecules in the water will move
    a. slower than they did before
    b. faster than they did before
    c. at the same speed as they did before

25. b

Complete each sentence by inserting the appropriate name.

Bernard Lovell   Isaac Newton   Count Rumford

Albert A. Michelson   Joseph John Thomson

1. **Isaac Newton** wrote the Law of Universal Gravitation.

2. **Joseph John Thomson** discovered that the particles that make up the cathode ray have a negative electrical charge.

3. **Albert A. Michelson** received the Nobel Prize for his accomplishment in measuring the speed of light.

4. **Count Rumford** did experiments involving friction.

5. **Bernard Lovell** is an astronomer who studies the stars with radio telescopes.

Unit 7: Life on Earth

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. Living things — 1. **b**
   a. create their own energy
   b. can only change energy into other forms
   c. use only the energy created by their cells

2. Of all the green plants found on our earth, — 2. **b**
   a. only 30% are found on land
   b. about 90% are found in the oceans
   c. about 40% are found in the oceans

3. The water-carrying tubes found in the leaves of plants are called — 3. **b**
   a. arteries
   b. veins
   c. capillaries

4. Carbon dioxide enters the leaf through the — 4. **a**
   a. stomata
   b. upper epidermis
   c. lower epidermis

5. Scientists who study chemical processes that occur in living things are 5. b
   a. ecologists
   b. biochemists
   c. physicists

6. Plants that grow on rocks are called 6. c
   a. chloroplasts
   b. stomata
   c. lichens

7. Green plants are needed to sustain 7. c
   a. only plant life
   b. only animal life
   c. all living things

8. For one inch of soil to be made, it takes about 8. b
   a. a hundred years
   b. a thousand years
   c. two hundred years

9. Grass will not grow in a thick forest for the main reason that 9. b
   a. the soil is too rocky
   b. it cannot get enough light
   c. the soil is too wet

10. Cactus plants can live with little rainfall because their roots 10. b
    a. grow deep into the soil
    b. spread out widely and absorb water near the ground surface
    c. are made up of large spongy cells

11. The chipmunk adapts to winter by 11. b
    a. breeding
    b. hibernating
    c. migrating

12. The blending in color of an animal's fur or skin with its surroundings is 12. a
    a. protective coloration
    b. migration
    c. protective hibernation

13. The changes in our environment take place 13. c
    a. rapidly
    b. very slowly
    c. both rapidly and slowly

14. Rachel Carson's book, *The Silent Spring,* was written mainly
    a. to warn the American people of what was happening to their country through the indiscriminate use of pesticides
    b. to tell the American people about the "ice age"
    c. to explain how fires ruin millions of acres of forest lands

14. **a** _ _ _ _ _

15. Conservation means
    a. using the earth's resources wisely
    b. the destruction of all poisonous plants and animals
    c. upsetting the balance of nature

15. **a** _ _ _ _ _

16. International Hydrological Decade, started in 1965, is a project aimed at
    a. studying the habits of migratory birds
    b. finding ways to prevent the loss of great amounts of water by evaporation and by other natural and man-made means
    c. studying the habits of predators

16. **b** _ _ _ _ _

17. There are about 500 forest fires in the United States each
    a. year
    b. day
    c. month

17. **b** _ _ _ _ _

18. A mixture of smoke and fog is called
    a. a pollutant
    b. dew
    c. smog

18. **c** _ _ _ _ _

19. Lichens give off carbon dioxide, which combines with water to form
    a. nitric acid
    b. carbonic acid
    c. chlorophyll

19. **b** _ _ _ _ _

20. An area set aside in which wildlife is protected is called a
    a. Gwamba
    b. refuge
    c. range

20. **b** _ _ _ _ _

Fill in the correct word for each sentence.

interdependent glucose predators chloroplasts lichens

1. **Glucose,** a form of sugar, is the product of photosynthesis.

2. **Chloroplasts** make chlorophyll from materials in the cell.
3. **Lichens** are plants that grow on rocks.
4. **Predators** are animals that attack other animals and eat them for food.
5. All living things are **interdependent.**

Unit 8: *How Animals Behave*

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. Scientists who study the behavior of animals are called — 1. **c**
   a. conservationists
   b. botanists
   c. ethologists
2. Studies of animal behavior indicate that the closer a stranger comes to the center of an animal's territory, — 2. **a**
   a. the fiercer the animal becomes
   b. the more gentle the animal becomes
   c. the hungrier the animal becomes
3. All the ways in which animals communicate with one another are called — 3. **b**
   a. chirping
   b. signaling
   c. vocalizing
4. The parts of an animal's nervous system stimulated by chemicals are — 4. **b**
   a. conductors
   b. chemoreceptors
   c. thermoreceptors
5. An example of a social insect is — 5. **b**
   a. a spider
   b. an ant
   c. a fly

6. The earthworm
   a. has light-sensitive cells at either end
   b. has no photoreceptors
   c. has a bright red eyespot

6. a

7. Cats have
   a. image-forming eyes
   b. compound eyes
   c. mosaic eyes

7. a

8. Animals that have slit pupils
   a. can see when there is very little light
   b. cannot get a sharp image of things
   c. have no rods in the retina of their eyes

8. a

9. Thermoreceptors are sensitive to
   a. changes in moisture
   b. changes in temperature
   c. changes in color

9. b

10. Mechanical receptors are sensitive to
   a. stimulation from touch, pressure, and sound
   b. changes in color
   c. changes in temperature

10. a

11. Ants find their way to a piece of sugar by
   a. using their well-developed eyes
   b. using the receptors for smell in their antennae
   c. feeling for the sugar with their legs

11. b

12. In the winter, bees may raise their body temperatures by
   a. collecting nectar
   b. flapping their wings and moving their feet
   c. buzzing around flowers and making honey

12. b

13. Karl von Frisch conducted experiments that
   a. explained reactions of one-celled animals to light
   b. increased our understanding of the behavior of the stickleback fish
   c. increased our understanding of communication among insects

13. c

14. Fish have a
   a. central nervous system
   b. inner nerve ring and tentacles
   c. nerve cord and "early" brain

14. a

15. The central nervous system — 15. b
    a. consists of the heart and spinal cord
    b. coordinates different body parts
    c. consists of the heart and brain

16. The hypothalamus controls — 16. a
    a. temperature and appetite in mammals
    b. vision in mammals
    c. light reception in mammals

17. Fish eat — 17. b
    a. more when the temperature is low
    b. less when the temperature is low
    c. without regard to temperature change

18. An animal that is a descendant of the family of *Canidae* is — 18. b
    a. a cat
    b. a dog
    c. a horse

19. A change in the structure of an animal that makes it easier for the animal to survive is called — 19. a
    a. an adaptation
    b. coordination
    c. sensory reception

20. Offspring of the family called *Felid*ae are — 20. a
    a. lions
    b. raccoons
    c. birds

Fill in the correct words or word for each sentence.

facets evaporation spinal cord survive acclimatized

1. Mosaic eyes are made up of separate small surfaces that scientists have named **facets.**

2. When animals adjust to temperature changes, we say that they have become **acclimatized.**

3. Animals that sweat or "pant" lose some of the water of their body by the process of **evaporation.**

4. The sensory equipment of an animal helps to equip the animal to **survive** its environment.

5. A central nervous system consists of a brain and a **spinal cord.**

Unit 9: *Science Today and Tomorrow*

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. The amount of scientific knowledge available to you
   a. is twice as much as was available to your father
   b. has not increased since your father was in school
   c. is 8 times as much as was available to your father

1. **c**

2. Study of the way in which living systems work is called
   a. bionics
   b. botany
   c. biochemistry

2. **a**

3. The science of cryogenics is concerned with
   a. temperatures in the Torrid Zone
   b. living tissues that are at very low temperatures
   c. temperature near absolute zero

3. **c**

4. At very low temperatures, electricity meeting no resistance is called
   a. conductivity
   b. ultraconductivity
   c. superconductivity

4. **c**

5. Absolute zero is
   a. minus 459.7° F.
   b. plus 459.7° F.
   c. 0° C.

5. **a**

6. Metals in a superconducting state
   a. repel a magnetic field
   b. attract a magnetic field
   c. react neutrally to a magnetic field

6. **a**

7. A liquid whose temperature is near absolute zero is called — 7. a
   a. a superfluid
   b. a subfluid
   c. an ultrafluid

8. Surgical operations using supercooled instruments are called — 8. a
   a. cryosurgery
   b. neurosurgery
   c. cardiovascular surgery

9. The laser is — 9. a
   a. brighter than the sun
   b. not as bright as the sun
   c. equal in brightness to the sun

10. Sound is measured by its frequency, which is expressed in — 10. b
    a. waves per hour
    b. cycles per second
    c. waves per second

11. The sound that humans hear lies within the range of — 11. b
    a. 1 to 100 cycles per second
    b. 16 to 20,000 cycles per second
    c. 16 to 4,000,000 cycles per second

12. A laser beam — 12. c
    a. goes back and forth in various directions
    b. fans out in a steadily enlarging cone
    c. is a narrow concentration of tremendous energy

13. The study of science in school will — 13. b
    a. enable everyone in your class to be a scientist
    b. enable you to better understand the world
    c. give you answers to almost all questions

14. A medical technologist is trained to — 14. b
    a. assist in hospital operating rooms
    b. conduct chemical, microscopic and other tests in hospital laboratories
    c. prepare drugs

15. A meteorologist — 15. a
    a. studies weather conditions
    b. studies life in the ocean
    c. is mainly concerned with behavior of plants and animals

16. Cryogenics means
    a. to make "red hot"
    b. to make "icy cold"
    c. to produce energy cheaply

16. **b**

17. Scientists are studying the frog's eye to learn
    a. how to develop an air defense system better than radar
    b. how to detect dangerous gases and spoiled foods
    c. how to develop and design better airplanes

17. **a**

18. The science of tomorrow probably will be concerned
    a. with many different problems of the world around us
    b. only with space exploration
    c. only with our national defense

18. **a**

19. Mathematics is
    a. important only to professional scientists
    b. important only in certain areas of science
    c. essential to understanding science

19. **c**

20. Today, most scientific work in our country is performed by
    a. individual men working alone
    b. NASA
    c. many teams or groups of scientists who work together

20. **c**

Fill in the correct word for each sentence.

biocell laser bionics ultrasonics cryobiologist

1. Using a liquid fuel and microorganisms such as bacteria, a **biocell** changes chemical energy directly into electrical energy.

2. A **cryobiologist** studies living tissues that are at very low temperatures.

3. The **laser** was developed by Dr. Theodore H. Maiman in 1960.

4. **Ultrasonics** is the science of sounds whose frequencies are above and below the range of human sensitivity.

5. **Bionics** is the study of living systems, to find out what makes them work.

Do You Remember?—Units 7, 8, 9

Select the best answer to complete each statement.
Write the letter of the answer in the space at the right.

1. Persons trained to manage timber, range, water, recreation, and wildlife resources are called — 1. b
   a. biologists
   b. Forest Rangers
   c. farmers

2. In the past fifty years, the population of the world — 2. b
   a. has stayed the same
   b. doubled
   c. tripled

3. A scientist who studies the chemical processes that take place in living things is called a — 3. a
   a. biochemist
   b. ethologist
   c. physicist

4. Animals that get their food by attacking and preying on other animals are known as — 4. b
   a. migrants
   b. predators
   c. hibernators

5. Chlorophyll, a green-colored chemical, is found in plant cells that are known as — 5. c
   a. stomata
   b. lichens
   c. chloroplasts

6. Light sensitivity and reaction to differences in brightness are characteristic of almost — 6. a
   a. all animals
   b. no mammals
   c. no animals

7. Animals with backbones have
   a. no rods in the retina of their eyes
   b. image-forming eyes
   c. mosaic eyes

b
7. _ _ _ _ _

8. Thermoreceptors are sensitive to
   a. physical changes in the surroundings
   b. changes in temperature
   c. chemicals

b
8. _ _ _ _ _

9. Your house cat is an offspring of the family called
   a. Miacidae
   b. Felidae
   c. Canidae

b
9. _ _ _ _ _

10. A change in the structure of an animal that makes it easier for the animal to survive is called
   a. an adaptation
   b. extinction
   c. an adoption

a
10. _ _ _ _ _

11. Green plants use energy from the sun to make
   a. glucose
   b. chlorophyll
   c. pepsin

a
11. _ _ _ _ _

12. The science that is concerned with temperatures that are near absolute zero is called
   a. bionics
   b. cryogenics
   c. biochemistry

b
12. _ _ _ _ _

13. The part of the brain in mammals that controls body temperature and appetite is known as the
   a. neutron
   b. medulla
   c. hypothalamus

c
13. _ _ _ _ _

14. The most important property of the laser beam is
   a. its narrow beam of greatly concentrated light
   b. its ability to travel in many directions
   c. its wide cone-shaped beam

a
14. _ _ _ _ _

15. A liquid whose temperature is near absolute zero is called
    a. a subfluid
    b. a superfluid
    c. an ultrafluid

15. b

16. Ultrasonics
    a. is the science of sounds whose frequencies may be heard by the human ear
    b. is the science of sounds whose frequencies are above and below the range of human sensitivity
    c. is the science of all sounds under water

16. b

17. The range of human sensitivity to sound is within
    a. 16 to 4,000,000 cycles per second
    b. 1 to 100 cycles per second
    c. 16 to 20,000 cycles per second

17. c

18. Changes in our environment take place
    a. very slowly
    b. rapidly
    c. both rapidly and slowly

18. c

19. Conservation means
    a. the careful management and use of our resources
    b. upsetting the balance of nature
    c. killing all harmful insects and animals in order that they will not harm us

19. a

20. The covering tissue of a leaf is the
    a. chloroplast
    b. stomata
    c. epidermis

20. c

21. Plants that grow on rocks are called
    a. predators
    b. lichens
    c. chloroplasts

21. b

22. The ability of different parts of an animal's body to function together is called
    a. conduction
    b. conservation
    c. coordination

22. c

23. The separate parts, or surfaces that together make up an insect's eye are known as
    a. plates
    b. facets
    c. biocells

23. b

24. The family of animals that includes wolves and dogs is called
    a. Felidae
    b. Canidae
    c. Miacidae

24. b

25. The ability of some animals, such as the bear, to sleep throughout the winter is known as
    a. hibernation
    b. migration
    c. insulation

25. a

Fill in the correct word for each sentence.

Theodore H. Maiman   Ráchel Carson   radiochemist

cyto-technologist   Karl von Frisch

1. **Karl von Frisch** did experiments with bees that increased our knowledge of the communication system among insects.
2. **Theodore H. Maiman** developed the laser in 1960.
3. **Rachel Carson** wrote about the indiscriminate use of pesticides in the United States.
4. A **cyto-technologist** examines cells for cancer.
5. A **radiochemist** measures the radioactivity in a substance.

Directory of Publishers of Science Books

American Association for the Advancement of Science, 1515 Mass. Ave., N.W., Washington, D.C., 20005
American Library Association, 50 East Huron St., Chicago, Ill., 60611
American Museum of Natural History, Central Park West at 79th St., New York, N.Y., 10024
Appleton-Century-Crofts, Inc., 34 West 33rd St., New York, N.Y., 10001
Basic Books, Inc., 59 Fourth Ave., New York, N.Y., 10003
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Encyclopaedia Britannica Press, 425 North Michigan Ave., Chicago, Ill., 60611
Field Enterprises Educational Corp., Merchandise Mart Plaza, Chicago, Ill., 60654
Follett Publishing Co., 1010 West Washington Blvd., Chicago, Ill., 60607
W. H. Freeman and Co., 660 Market St., San Francisco, Calif.
Garrard Press, 510–522 North Hickory St., Champaign, Ill., 61820
Ginn & Co., 72 Fifth Ave., New York, N.Y., 10011
Golden Press, Inc., 850 3rd Ave., New York, N.Y., 10020
Grolier Inc., 575 Lexington Ave., New York, N.Y., 10022
Grosset & Dunlap, Inc., 1107 Broadway, New York, N.Y., 10010 (Mail orders to 227 East Center St., Kingsport, Tenn., 37660)
Harcourt, Brace and World, Inc., 750 Third Ave., New York, N.Y., 10017
Harper & Row, Publishers, 49 East 33rd St., New York, N.Y., 10017
D. C. Heath and Company, 285 Columbus Ave., Boston, Mass.
Holt, Rinehart and Winston, Inc., Publishers, 383 Madison Ave., New York, N.Y., 10017
Houghton Mifflin Co., 2 Park St., Boston, Mass., 02107
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International Publishers, 381 Park Ave. South, New York, N.Y., 10017
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Lane Book Company, Menlo Park, Calif., 94025 (Distributed by Lippincott in all states east of Idaho, Utah, and Arizona)
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William Morrow and Co., Inc., 425 Park Ave. South, New York, N.Y., 10016

C. V. Mosby Company, 3207 Washington Blvd., St. Louis, Mo.

National Geographic Society, Department FBJ, 1146 16th St., N.W., Washington, D.C., 20036

National Science Teachers Association, 1201 16th St., N.W., Washington, D.C., 20006

Thomas Nelson & Sons, 18 East 41st St., New York, N.Y., 10017

The New American Library of World Literature, Inc., 501 Madison Ave., New York, N.Y., 10022

Frederick A. Praeger, Inc., 111 Fourth Ave., New York, N.Y., 10003

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Scott, Foresman and Co., 433 E. Erie St., Chicago, Ill.

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University of Chicago Press, 5750 Ellis Ave., Chicago, Ill., 60637

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Franklin Watts, Inc., 575 Lexington Ave., New York, N.Y., 10022

H. W. Wilson Co., 950 University Ave., New York, N.Y., 10052

World Publishing Co., 119 West 57th St., New York, N.Y., 10019

Directory of Film and Filmstrip Sources

Audio-Visual Communication Review, Dept. of Audio-Visual Instruction, Washington, D.C.

Blue Book of Audio-Visual Materials (annual), Educational Screen, Inc., 64 E. Lake St., Chicago, Ill.

A Directory of 16mm Film Libraries, U.S. Department of Health, Education and Welfare; U.S. Government Printing Office, Washington, D.C.

Education Film Guide (annual), The H. W. Wilson Co., 950 University Ave., New York, N.Y.

Educators Guide to Free Films (annual), Educators Progress Service, Randolph, Wisc.

Modern Index and Guide to Free Educational Films from Industry (annual), Modern Talking Picture Service, Inc., 3 E. 54th St., New York, N.Y.

U.S. Government Films for Public Educational Use, 1955, Office of Education, U.S. Department of Health, Education and Welfare; U.S. Government Printing Office, Washington, D.C.

U.S. Government Films for Schools and Colleges (annual), United World Films Inc., 1445 Park Ave., New York, N.Y.

Directory of Science Materials Supply Houses

American Hospital Supply Corp., 40–05 168th St., Flushing, Queens, N.Y.; or Evanston, Ill. (blood-typing serums, standard supplies)

American Optical Co., Buffalo, N.Y. (optical instruments)

American Type Culture Collection, 2112 M St., N.W., Washington, D.C. (bacteria)

Bausch & Lomb Optical Co., 635 St. Paul St., Rochester, N.Y. (optical instruments)

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Cambosco Scientific Co., 37 Antwerp St., Brighton, Mass.

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Fisher Scientific Co., Forbes Ave., Pittsburgh, Pa. (chemicals, laboratory appliances)

General Biochemicals, Inc., 677 Laboratory Park, Chagrin Falls, Ohio (chemicals)

General Biological Supply House, Inc. (Turtox), 8200 S. Hoyne Ave., Chicago, Ill.

Kimble Glass, P.O. Box 1035, Toledo, Ohio (glassware)

Lederle Laboratories, Div. of American Cyanamid Co., Middletown Rd., Pearl River, N.Y. (chemicals)

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Los Angeles Biological Laboratory, Supply Dept., Woods Hole, Mass. (living and preserved materials)

Monsanto Chemical Co., 1700 S. Second St., St. Louis, Mo. (chemicals)

National Biological Supply Co., Inc., 230 W. Superior St., Chicago, Ill.

New York Scientific Supply Co., Inc., 28 W. 30th St., New York, N.Y.

Research Scientific Supplies, Inc., 69 W. 23rd St., New York, N.Y. (microscopes, microslides, stains)

E. H. Sheldon Equipment Co., 101 Park Ave., Rm. 538, New York, N.Y. (laboratory furniture)

Spitz Laboratories, Yorklyn, Dela. (shadowboxes, plasteria)

Sprague-Dawley, Inc., P.O. Box 2071, Madison, Wisc. (laboratory rats)

Standard Scientific Supply Corp., 808 Broadway, New York, N.Y.

Triarch Botanical Products, Ripon, Wisc. (botanical microslides)

Wards Natural Science Establishment, Inc., P.O. Box 1712, Rochester, N.Y.

Welch Scientific Co., 1515 Sedgwick St., Chicago, Ill. (scientific apparatus)

SOME OF THE SPECIAL FEATURES YOU'LL FIND IN SCIENCE FOR TOMORROW'S WORLD, BOOK 6:

A Picture Story

BOOK 6 features a full-color photographic study that shows scientists at work in today's world. More than just an attractive picture sequence, this story contains *why* and *how* information and gives the pupils a "behind the scenes" knowledge of:

Conservation in Action (pages 278-286)

Pathfinders in Science

To help the pupils understand science as a human enterprise, eight of the units in BOOK 6 include this unique section. Some of the "Pathfinders in Science" sections give facts about their subjects' lives and scientific careers. All of them spotlight problems solved through science.

Friedrich Wilhelm Bessel (see pages 24 and 25) makes the direct measurement of distances to the nearer stars possible.

Benjamin Thompson, also known as Count Rumford, (see pages 46 and 47) uses basic research as the groundwork for scientific development.

Sir Isaac Newton (see pages 86 and 87) questions old ideas and gives the world much new scientific knowledge.

Joseph John Thomson (see pages 104 and 105) discovers particles called *electrons* within every atom.

A. C. Bernard Lovell (see pages 180 and 181) uses the radio telescope to discover new kinds of stars.

Albert A. Michelson (see pages 198 and 199) measures the speed of light more precisely than anyone else.

Rachel Carson (see pages 264 and 265) warns the American people of the dangers of the indiscriminate use of pesticides.

Karl von Frisch (see pages 320 and 321) increases our understanding of communication among insects.

Active learning experiences

BOOK 6 provides an abundance of open-ended investigations, including experiments, observations, and demonstrations. All of these activities require only simple, inexpensive equipment. For each, the text explains exactly what will be needed and how the pupils can solve a problem or answer a question. Notice that neither the text nor the illustration ever "gives away" the results. (For examples, see pages 72, 99, 172, 220, and 319.)

At the end of every major division in a unit, a "Using What You Have Learned" section gives the pupils more opportunities to learn the methods of science firsthand. (See pages 31, 70, 124, 168, 200, and 367.)

More review and reinforcement materials than any other sixth-grade science textbook

SCIENCE FOR TOMORROW'S WORLD, BOOK 6, aims at getting facts and concepts into every pupil's head. It aims at *understanding,* not memorization.

After every unit, the "What You Know About ......" (fill in unit title) pages provide a summary of the learnings in the unit, a checklist of science words, and objective tests. (See pages 32, 58, 92, 138, and 188.) Then the "You Can Learn More About ......" pages offer a variety of reinforcement activities that include projects and up-to-date lists of supplementary science books. (See pages 34, 60, 94, 140, and 190.)

"Do You Remember?" is a unique summary section, which appears in the middle of the text (page 232) and again at the end (page 388). Far more than a mere re-telling of the facts, this section pulls together specific concepts and points in the direction of the Key Concepts that reflect the whole underlying structure of science.

Meaningful illustrations—no "frills"

SCIENCE FOR TOMORROW'S WORLD, BOOK 6, is illustrated in four colors throughout. And all of the illustrations—drawings, photographs, diagrams—are scientifically accurate and directly related to the discussions and activities in the text. See, for example, how the following topics are clarified by illustrations:

Methods of measuring things—Drawings on pages 2, 3, 12, 21, 34, 35
- Photographs on pages 1, 2, 8, 31
- Diagrammatic drawings on pages 4-6, 11, 15, 22, 24, 26, 28, 29
- Illustrations of activities on pages 9, 10
- Graphs on pages 17, 18, 19, 27, 30

Electricity and electronics—Drawings on pages 99, 106, 114, 126, 140, 141
- Photographs on pages 96-98, 102, 111, 115, 123, 133-136
- Diagrammatic drawings on pages 99-101, 103, 105, 107-110, 112, 113, 117-122, 127-132
- Illustrations of activities on pages 124, 139-141

The nature of light—Drawings on pages 194, 203, 204, 231
- Photographs on pages 192, 193, 223
- Diagrammatic drawings on pages 195, 197, 198, 202, 204, 205, 212, 216, 219, 223, 225
- Illustrations of activities on pages 196, 200, 201, 206-211, 213, 215, 217, 218, 220, 221, 222, 224, 226, 227, 229-231

IN THE BACK OF THE TEXT YOU WILL FIND:

An illustrated "Dictionary of Science Words"
A "Dictionary of Scientists"
A "Checklist of Science Activities"
The Index

The Macmillan Science Series

10829